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KINZUA DAM, ALLEGHENY RIVER PENNSYLVANIA AND NEW YORK

Hydraulic Model Investigation

by

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A hydraulic model of Kinzua Dam, Pennsylvania, was used to evaluate various methods of preventing riverbed material from entering the stilling basin and causing erosion problems. Major spillway rehabilitation projects required in 1973 and again in 1983 prompted this study. Holes in the stilling basin concrete up to 25 ft in diameter and 42 in. deep were noted. The rock trap selected as the final design was constructed in the prototype in the fall of 1983 and has been most effective in keeping material out of the basin to date. Strict adherence to the sluice gate operating schedule has been enforced and has also contributed to the success of the final solution.

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PREFACE

The model investigation reported herein was authorized by the US Army Engineer District, Pittsburgh (ORP), in September 1982. The studies were conducted by personnel of the US Army Engineer Waterways Experiment Station (WES) Hydraulics Laboratory during the period November 1982 to October 1983. The investigation was conducted under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the direct supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. The tests were conducted by Messrs. W. B. Fenwick and J. Rucker under the general supervision of Mr. S. T. Maynord, all of the Spillways and Channels Branch. This report was prepared by Mr. Fenwick and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

During the course of this investigation, Messrs. R. W. Schmitt, E. R. Kovanic, and G. C. Coletti, ORP; R. C. Armstrong, G. Drummond, and L. Varga of the US Army Engineer Division, Ohio River; and T. Munsey of the Headquarters, US Army Corps of Engineers, visited WES to observe model tests and to correlate these results with concurrent design work. Mr. Schmitt served as District Coordinator and contributed to this report.

Acting Commander and Director of WES during preparation of this report was LTC Jack R. Stephens, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to metric SI (metric) units as follows:

Multiply	By	To Obtain
acres	0.4047	hectares
acre-feet	1,233.489	cubic metres
cubic feet	0.02832	cubic metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
feet of water	0.03048	kilograms per square centimetre
inches	2.54	centimetres
miles (US statute)	1.609	kilometres
pounds (force)	4.448222	newtons
square miles	2.589998	square kilometres

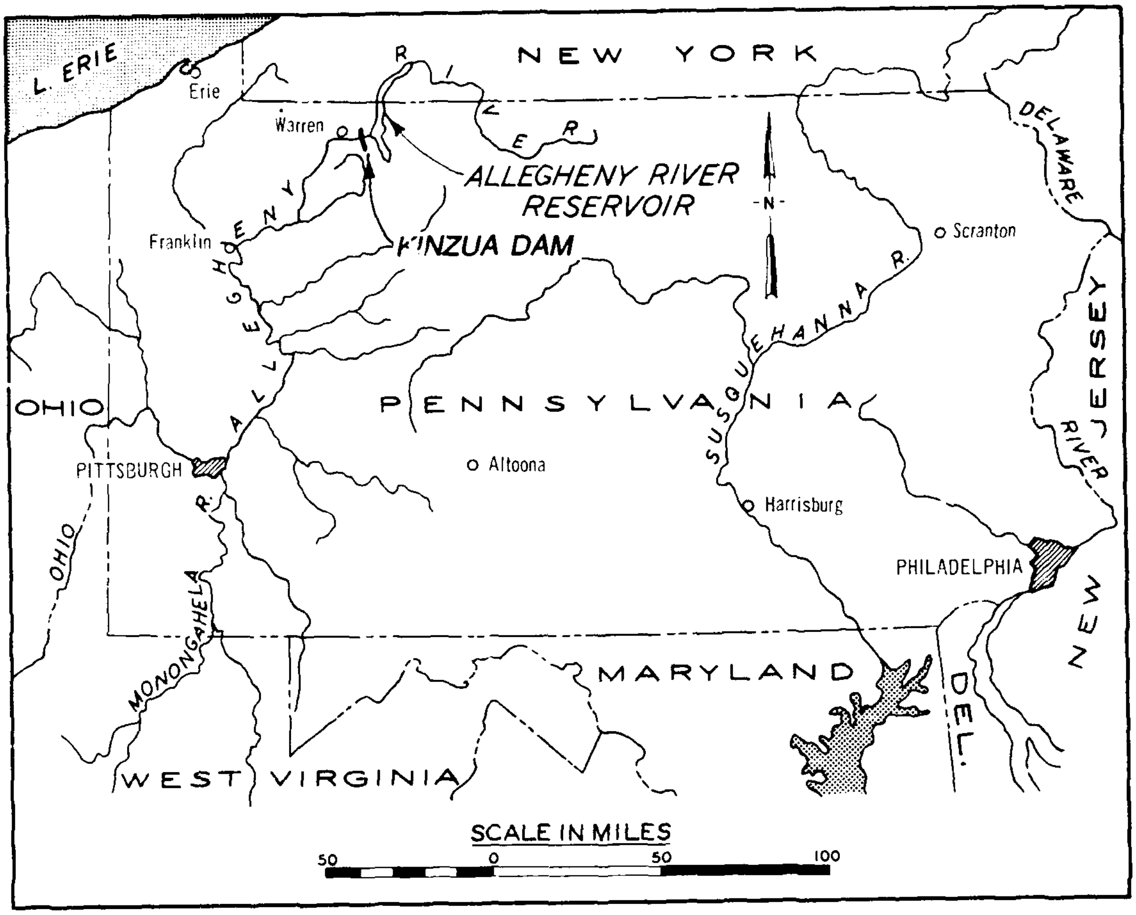

Figure 1. Location map

KINZUA DAM, ALLEGHENY RIVER, PENNSYLVANIA AND NEW YORK

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype*

General features

1. Kinzua Dam and Allegheny Reservoir were authorized by the Flood Control Acts of 1936 and 1938. Kinzua Dam, located on the Allegheny River, was completed in 1965 by the US Army Engineer District, Pittsburgh. The Allegheny Reservoir, one of 16 major flood-control reservoirs in the Pittsburgh District, provides substantial flood-control reduction in the Allegheny and Upper Ohio River valleys. Previous model studies were conducted at the US Army Engineer Waterways Experiment Station (WES) for this project in 1960-1961** and 1975-1976.† The reservoir is located in Warren and McKean Counties, Pennsylvania. The damsite is approximately 200 miles†† above the junction of the Allegheny and Monongahela Rivers at Pittsburgh (Figure 1). The dam is a combination concrete gravity structure and rolled earth-fill embankment, and is 1,909 ft long with a maximum height of about 175 ft (el 1,375‡) above the riverbed (Plate 1). The reservoir controls a drainage area of 2,180 square miles and has a total storage capacity of about 1,125,000 acre-ft at reservoir full el 1,365 (surface area 21,000 acres or 32.8 square

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* Information in this section was obtained from design memorandums prepared by the US Army Engineer District, Pittsburgh.

** US Army Engineer Waterways Experiment Station. 1963 (Mar). "Spillway and Sluices, Allegheny Dam, Allegheny River, Pennsylvania and New York; Hydraulic Model Investigation," Technical Report 2-621, Vicksburg, MS.

† Herman O. Turner, Jr. 1976 (13 May). "Summary Report of Model Tests for Kinzua Dam Stilling Basin and Getaway Channel" (unpublished letter report), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

†† A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 3.

‡ All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

miles). Full operation of the project began in January 1967. Since its completion in 1965, Kinzua has prevented flood damages estimated in excess of $323 million.

Spillway

2. The spillway section of the dam is 204 ft wide and its crest is at el 1,341. The ogee crest is designed to conform to the nappe from a head of 22 ft, although it will accommodate the maximum expected head of 29 ft. Spillway flow is regulated by four 45-ft-wide by 24-ft-high tainter gates.

Outlet works

3. The outlet works consists of two high-level and six low-level rectangular sluices, each 5 ft 8 in. wide by 10 ft high (Plates 1 and 2), with the inlets protected by trashracks. The two high-level sluices, with inverts at el 1,300, provide for withdrawal of the warmer water in the upper portion of the reservoir during the summer recreation season. A maximum conservation flow of about 3,600 cfs, which is desired during the summer months, is supplied by these two sluices at reservoir el 1,328. Each high-level sluice is controlled by a single slide gate with provision for emergency closure at the face of the dam. Vents 18 in. in diameter are located immediately downstream of the service gates.

4. The six low-level sluices have horizontal inverts at el 1,205 with flared exits containing tetrahedral deflectors. Each sluice has an emergency and a service slide gate in tandem, with provision for bulkheads at the face of the dam. Air vents through the conduit roofs immediately downstream from the service gates are served by 30-in.-diam pipes. The six low-level sluices are used to pass regulated flows in the interest of flood control, to draw down the reservoir if required, and to augment the spillway in passage of the design flood. Bank-full capacity, 25,000 cfs, can be discharged through these sluices at reservoir el 1,325.

5. In 1969, the Pennsylvania Electric Company installed a 400-Mw pumped storage generating plant on the left bank of the river that uses an 800-ft plateau for storage. Discharges up to 4,000 cfs are used when the plant is generating. Dam gates are adjusted to compensate for power releases to maintain constant flow releases and downstream river stages.

Stilling basin

6. The hydraulic jump type stilling basin consists of a 160-ft-long, 204-ft-wide horizontal apron at el 1,180, surmounted by a single row of

7-ft-high baffle piers placed 102.5 ft from the beginning of the apron, and terminated with a 10-ft-high vertical-faced end sill. The baffle piers are 8 ft wide and spaced 8.5 ft apart. The vertical training walls have a top elevation of 1,230, and are terminated by a section extending 60 ft downstream from the end sill with its top sloping from el 1,230 to el 1,205.

Purpose and Scope of Model Study

7. The purpose of the model study was to evaluate various methods of sluice operation for preventing riverbed material from entering the stilling basin and causing recurrent abrasion and erosion problems. Adverse currents (return eddies) have brought bed material back into the basin and eroded holes up to 25 ft in diameter and 42 in. deep in the concrete. It was necessary to rehabilitate (repave) the stilling basin first during the 1973-1974 construction seasons and again in 1983. These occurrences necessitated the present model study. Various sluice operational modes were evaluated along with structural modifications such as debris traps and sloping end sills. The discharge ends of the upper sluices were modified in several ways in an attempt to eliminate the circular current patterns in the stilling basin. The model was also used to confirm satisfactory performance of the spillway and stilling basin during passage of the design flood.

PART II: THE MODEL

Description

8. The 1:30-scale model (Photo 1 and Plate 3) reproduced a 445-ft-wide section of the approach, the entire spillway and portions of each abutment, the two high-level and six low-level sluices, the stilling basin, the powerhouses, and a 400-ft-wide section of the exit channel.

9. The headbay box was made of plywood and simulates a prototype portion of the reservoir 445 ft wide by 445 ft high by 195 ft deep. The dam was installed in an opening through one wall. The floor of the headbay was at el 1,145 and the spillway crest was at el 1,341. The tainter gates, spillway, and crest were constructed of sheet metal. The crest was made of a bottom and a top section and joined together as shown in Photo 2. The six lower sluices were constructed of plastic and installed through the lower crest section. The two upper sluices were also plastic and were installed through plywood boxes on each side of the crest. A downstream view of the completed structure is shown in Photo 3. The sluice entrances can be seen in this photograph.

10. The stilling basin and training walls were made of waterproof plywood. The downstream surface of the model was molded of concrete mortar to sheet metal templates set at elevations 6 ft lower than those shown in the 1981 survey. The exact surface elevations were then molded with a coarse sand-pea gravel mix. This resulted in the availability of a 6-ft prototype depth of material over the entire bed available for movement during tests. Figure 2 shows a gradation curve for the material, which represents riverbed material in the 3/4- to 8-in. range.

11. Water used in the operation of the model was supplied by a recirculating system. Discharges were measured by venturi meters installed in the flow lines and were baffled when entering the model headbay. Tailwater elevations were controlled by an adjustable tailgate.

Scale Relations

12. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General

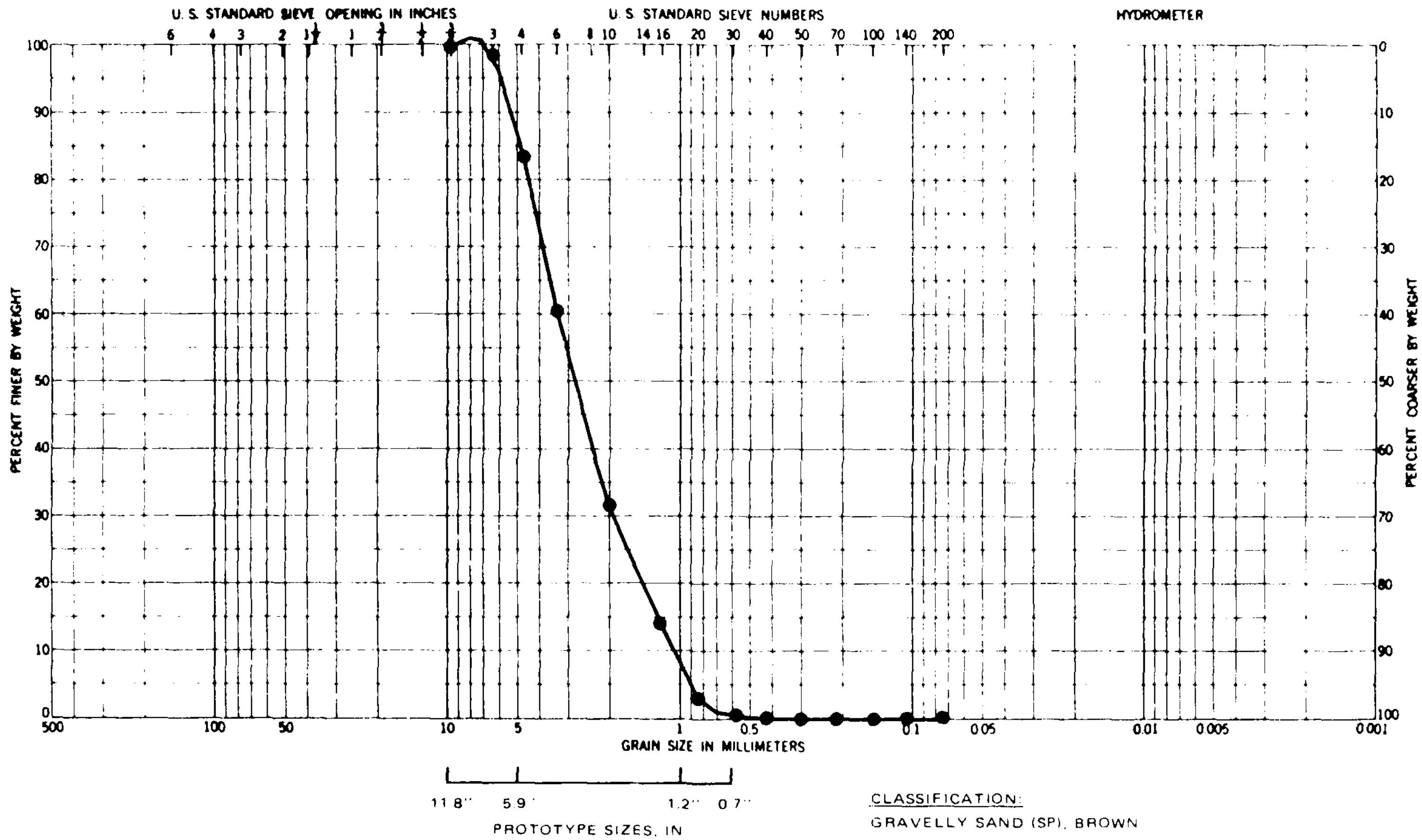


Figure 2. Gradation curve for riverbed material

relations for the transference of model data to prototype equivalents are presented below:

Characteristic	Dimensions*	Scale Relations Model:Prototype
Length	L_r	1:30
Area	$A_r = L_r^2$	1:900
Velocity	$V_r = L_r^{1/2}$	1:5.477
Discharge	$Q_r = L_r^{5/2}$	1:4,929.5
Volume	$V_r = L_r^3$	1:27,000
Weight	$W_r = L_r^3$	1:27,000
Time	$T_r = L_r^{1/2}$	1:5.477

* Dimensions are in terms of length.

Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype equivalents by the scale relations. Experimental data also indicate that the model-to-prototype scale ratio is valid for scaling stone in the sizes used in this investigation.

PART III: TESTS AND RESULTS

Model Calibration

13. Preliminary testing of the eccentric gate operation mode demonstrated the capability of the model to move the riverbed material readily into the stilling basin. The riverbed was remolded to 1981 contours following each test. Results of these tests are shown in the following tabulation:

Total Gate	Sluice		Operation Time	Volume Material
Opening, ft	Number*	Opening, ft	prototype hours**	Moved, yd^3
10	8	10	2.74	88
10	8	10	2.74	39
12	8, 6	6 each	2.74	7

* Looking downstream, the lower sluices are numbered 3 through 6 from left to right with numbers 1 and 2 being the upper sluices.
** 30 min model time.

It was quite evident from even these short-term tests that eccentric sluice operation caused considerable quantities of material to be moved into the stilling basin.

14. Following the limited eccentric sluice operation tests, selected conditions were tested from the then-current operating schedule dated 1 October 1979. Table 1 presents the results of these tests. It can be seen that, of the conditions tested, only the operation of all six lower sluices fully open caused material to enter the stilling basin. Some tests were repeated for 5 hr (55 min model time) instead of the initial 2.74 hr. It was apparent at this point that no amount of operating schedule manipulation would be adequate to prevent material from entering the basin. The study of various structural additions or modifications was initiated at this time.

Rock Trap Tests

15. Table 2 presents results of the initial symmetrical sluice

operation, rock trap, and sloping end sill tests. Based on these results, the rock trap was better than the symmetrical sluice operation or the sloping end sill at keeping rock out of the stilling basin. It was decided that model tests of seven continuous prototype days (30.7 hr in model) should be used to evaluate trap effectiveness.

16. Test results of five rock trap configurations are shown in Table 3. The type 1 design trap was intended to simulate capping the cofferdam (built to effect basin repairs) at el 1,194 and using it as the downstream trap wall. The type 2 design trap contained a wall immediately upstream of the cofferdam at el 1,190 (same as end sill). Types 3, 4, and 5 design traps were provided by the Pittsburgh District. Based on the data shown, the type 2 design trap was the most effective in trapping the loose rock being transported by the flow from the exit channel toward the stilling basin. Due to top of rock contours downstream of the end sill, the final design of the rock trap was as shown in Plate 4. This trap will function similar to the type 2 trap except that it will have less volume available to trap material. Spillway operation at a discharge of 114,000 cfs was found to be satisfactory with the trap installed (Photo 4a). The flow was contained within the stilling basin and any stone present in the basin was swept out. Photo 4b shows a dry bed view of the rock trap. The cut section near the center of the trap wall was used in wall load tests as described later.

Lower Sluice Modification

17. Primarily for comparative purposes, the tetrahedral deflectors were removed from the lower sluice outlets for two tests. The results of these tests are as follows:

Total Gate Opening, ft	Sluice		Tailwater El	Operation Time, prototype days	Volume of Material Moved, yd^3	
	Number	Opening, ft			Basin	Trap
28	4,5,6,7	7 each	1,205.5	4	45	0
20	7,8	10 each (full)	1,204.8	4	1,045	3,120

It can be seen by comparing the results of these tests with results of similar tests (Table 3) that this was a detrimental structural modification, which resulted in large quantities of loose stone being transported into the basin and trap.

Riprap Armoring

18. Test results indicated that operation with gates 7 and 8 each open 10 ft (full) was the worst eccentric operating mode that could occur. This condition is shown in Photo 5. Photo 6 shows the results after 4 prototype days of operation. The basin contained 840 yd^3 of loose stone and the trap contained 530 yd^3. Using the same gate configuration, tests were conducted to develop the criteria for placing an armor layer of riprap downstream of the rock trap. The results of these tests are shown in the following tabulation. All tests were run for 7 days with gates 7 and 8 each fully open.

Armor Stone Size, in.	Extent of Downstream Coverage, ft	Results
15-23	100	Scoured 40-ft-diam hole in riprap. Ten pieces riprap and less than 1 yd^3 rock in trap. Small amount of fine rock in basin
23-37	100	Washed 40- by 25-ft hole in riprap. Twenty-four pieces riprap and 5 yd^3 in trap. About 3 yd^3 in basin (mostly fine rock)
37-45	200	No damage. Less than 1 yd^3 in trap. None in basin
37-45	100	No damage. Less than 1 yd^3 in trap. None in basin
37-45	100 (without underlying filter cloth)	No damage. Less than 1 yd^3 in trap. None in basin

It can be seen that a layer of 3-4 ft of riprap would be required for a distance of about 100 ft downstream of the trap to provide a stable armored bottom. In the event the trap is not a completely satisfactory solution to the problem, future consideration should be given to complete armor protection.

Upper Sluice Modification

19. Operation of the upper sluices with rock present in the stilling

basin is believed to be a major cause of the concrete erosion in the stilling basin floor. Circular flow patterns were created that readily moved the washed-in downstream bed material around in the basin. Photo 7 shows the two upper sluices fully open. Several simple modifications to the exit opening for the upper sluices were evaluated in the model. Several sizes of blocks were installed in the sluice exit openings and served as flow deflectors. The various configurations are shown in Plate 5. These modifications were successful in moving the discharge impact spot around on the spillway slope. Flow conditions with modification 6 on the right side are shown in Photo 8. This modification was the most desirable of those tested. The sluice in the left of Photo 8 is unmodified. Baffle walls 15 ft high (pier extensions) are visible in Photo 8 on both sides of the spillway. It can be seen that the discharge from the unmodified sluice is partially clearing the wall. Pier extensions would obviously have to be used only in conjunction with some type of sluice deflector that would lower the discharge jet.

20. Additional upper sluice modification tests were conducted by attaching a door to the upper sluice opening. The door was hinged on the downstream edge of the opening. Photos 9 through 13 show the sluice in modification 1 operating with the door in various positions. It can be seen from these photos that with the door closed 90 deg or more from the downstream training wall, the flow was distributed fairly uniformly on the spillway slope. Because very little flow was noted near the wall, the door was modified in an attempt to get more even distribution. The door was cut in half diagonally and the lower upstream half was removed for one test. This same cut line was curved for two other tests, resulting in a concave and a convex upstream door edge. All three performed very well when closed at least 90 deg. In addition to these tests, several screen or grid covers over the sluice opening were evaluated, but none provided significant flow distribution improvement. It is recognized that a door on the sluice opening closed 90 deg or more would restrict flow somewhat; but since these sluices seldom operate at full capacity, discharge adjustments could be made.

Operational Schedule for Lower Sluices

21. Based on the results of model testing, the following operating schedule for the lower sluices is recommended:

Total Opening Required to Pass Outflow from Dam, ft	Operating Schedule*
0-12	5,6 or 4,7
0-20	3,8
21-30	3,6,8 or 3,5,8
21-40	3,4,7,8
41-60	3,4,5,6,7,8

* Gates listed under each operation mode have the same opening.

It is felt that these operational modes provide the least likelihood of material entering the trap and/or stilling basin. Opening and closing of the sluices must be done in increments of 1/2 ft or less to prevent eccentric flow patterns from developing. Sluices 3, 5, 6, and 8 are open 7 ft each in Photo 14. Photo 15 shows the same flow from sluices 4, 5, 6, and 7 but with much worse flow conditions resulting. Appendix A is the recommended operation schedule (dated 1 September 1983) for use when all gates are operative. This schedule was prepared on the basis of all tests, many of which are not shown in this report, made in the model as well as others that have been observed in the prototype. Gate operators should be cautioned that adherence to this schedule and the recommended incremental opening should be strictly followed.

Wall Load Tests

22. A 10-ft-wide section of the rock trap wall was isolated and instrumented with strain gages to estimate the overturning forces that were exerted on the wall. With a spillway flow of 114,000 cfs and a tailwater elevation of 1,226, an upstream force of about 1,300 lb per linear foot of wall was measured. Measurements were also made with sluices 4, 5, 6, and 7 open 10 ft each. An upstream force of about 1,400 lb per linear foot and a downstream force of about 500 lb per linear foot were recorded. These forces would be represented by a horizontal point force near the top of the wall.

Cofferdam Tests

23. Tests were conducted to determine if it would be advantageous to retain the cofferdam used to repair the prototype stilling basin as the retaining wall for the rock trap. The cofferdam was constructed just downstream of the end sill. The stilling basin was dewatered to make repairs and to construct the rock trap as shown in Plate 4. Velocity measurements were made in the model for several test conditions while the cofferdam was in place. The first test was with sluices 3 and 8 each fully open (10 ft) and tailwater el 1,204.8. Surface velocities were measured across the channel about 8 ft upstream and 70 ft downstream of the cofferdam. Bottom velocities were also measured 70 ft downstream. Test results are shown in Figure 3.

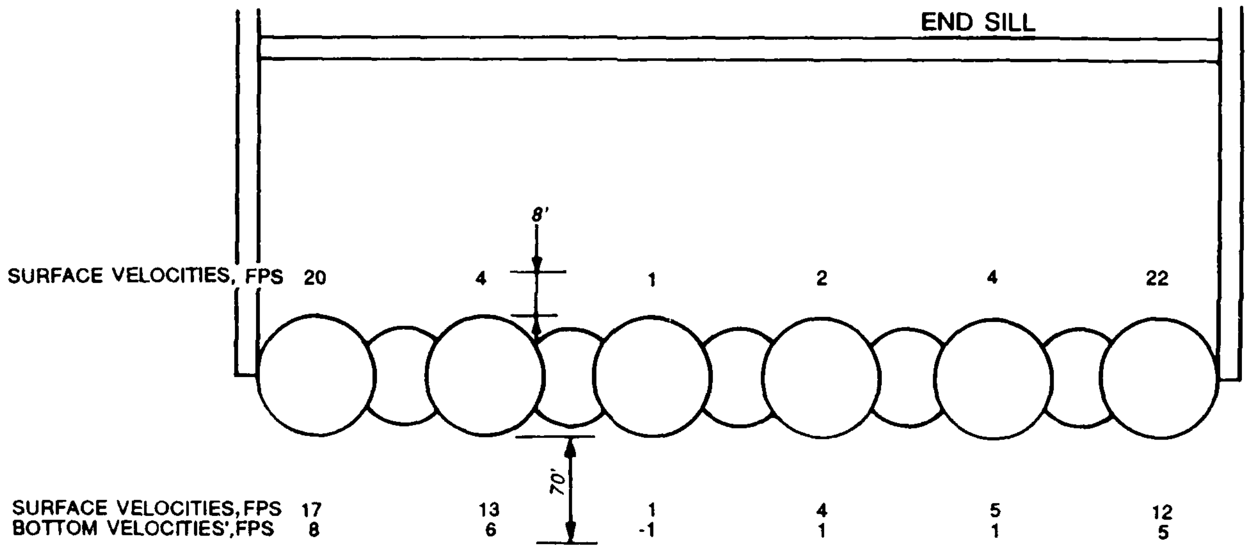


Figure 3. Sluices 3 and 8 fully open (10 ft each), tailwater el 1,204.8

Sluices 3, 4, 7, and 8 each fully open were tested next with a tailwater elevation of 1,207.5. Velocities obtained are shown in Figure 4. Velocity profiles at 3-ft depth intervals were obtained for sluices 3, 4, 5, 6, 7, and 8 fully open (10 ft) and a tailwater elevation of 1,209. Results are shown in Figure 5. It was concluded from these tests that the cofferdam should be removed after completion of construction.

24. In June 1984 it was reported that upper sluice gate 2 had a bent stem. A brief test was conducted to determine the effect of operating the No. 1 sluice alone. With No. 1 fully open the flow pattern shown in the

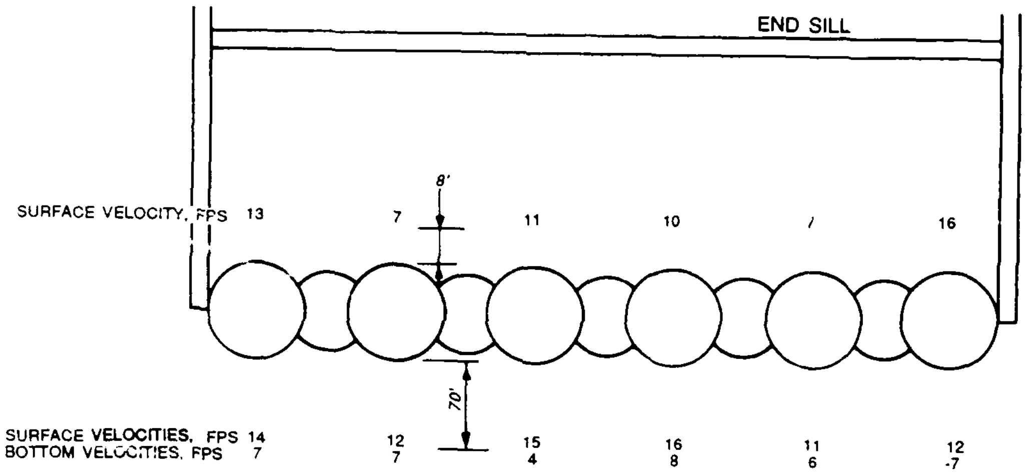


Figure 4. Sluices 3, 4, 7, and 8 fully open (10 ft each), tailwater el 1,207.5

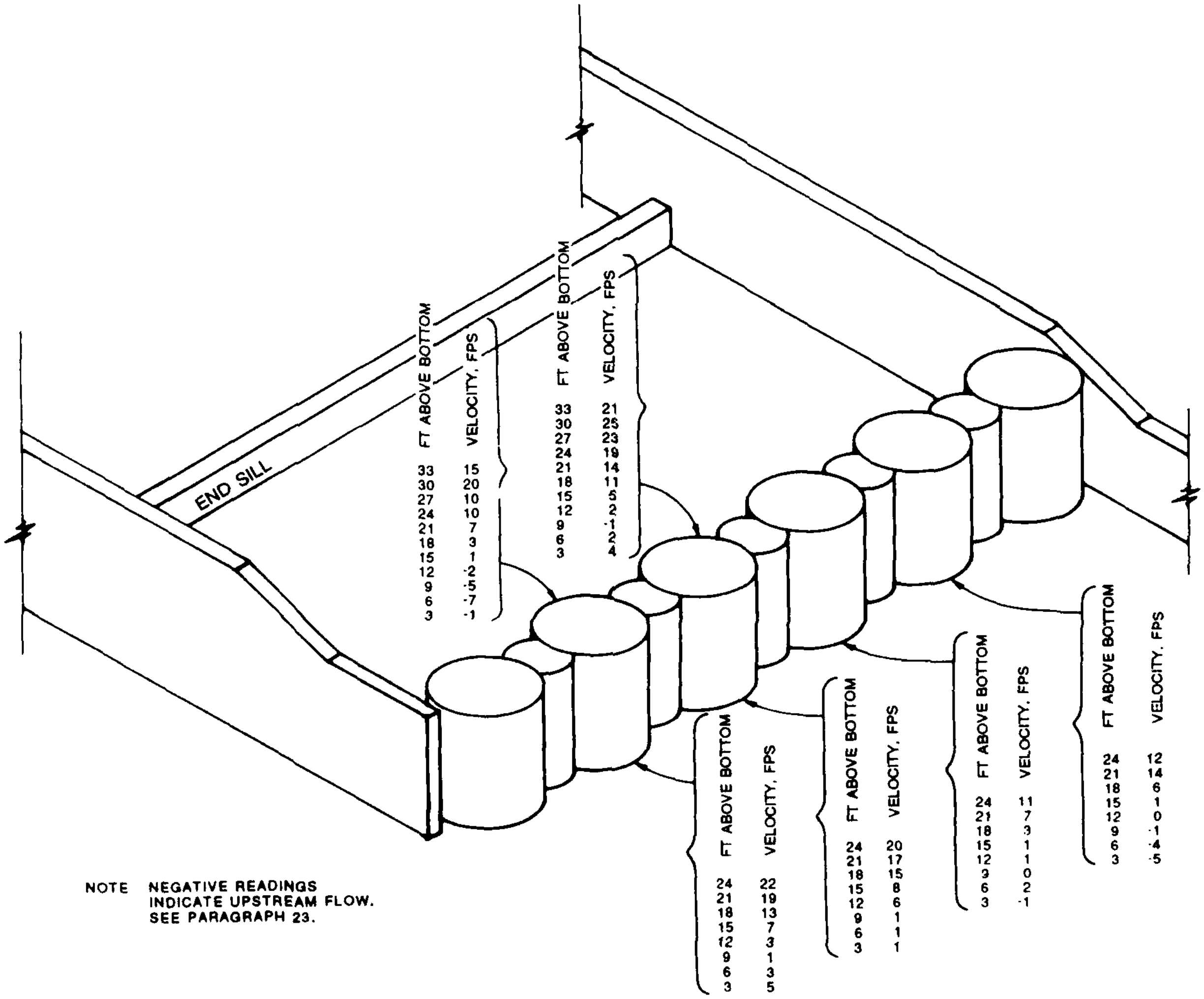
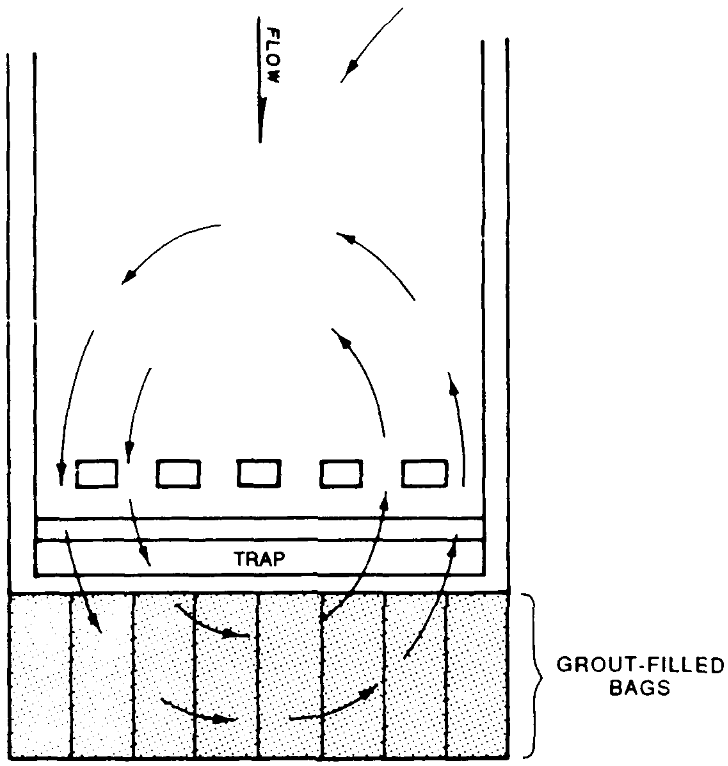


Figure 5. Sluices 3, 4, 5. 6, 7, and 8 fully open (10 ft each), tailwater el 1,209

following sketch was noted. Although velocities were not measured, it was apparent from dye tests that velocities were much too low to move any material located downstream of the trap. Some pea gravel was scattered over the floor of the stilling basin. After operating the model for about 30 min, all this material was gathered near the center of the basin. It was concluded that brief periods of operating No. 1 sluice alone would not be harmful.



Grout-Filled Bags

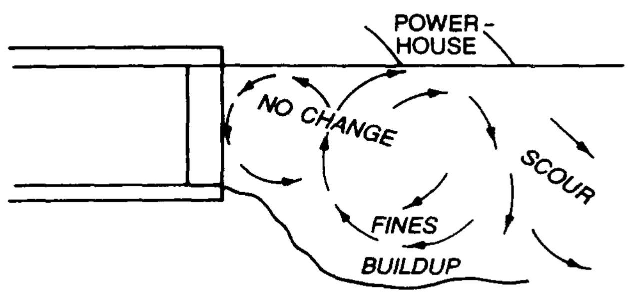
25. Tests were conducted with grout-filled bags instead of riprap downstream of the trap to reduce or eliminate the supply of downstream material in the event of progressive accumulation of material or gate misoperation. The bags were 3 ft thick, 7 ft wide, and 20 ft long and were placed with the long side parallel to the flow. A distance of 120 ft downstream of the trap had to be covered to minimize scour and movement of material. These bags are shown in the model covering a length of 100 ft downstream of the trap in Photo 16. Several tests were conducted with 100 ft of the bags in place. Sluices 7 and 8 fully open for 7 days (Photo 17) resulted in about 5 yd^3 of material in the trap. Severe scour occurred downstream of sluices 7 and 8. Sluices 7 and 8 fully open with a length of 120 ft of

grout-filled bags caused severe scour, but no material was moved into the trap. Sluices 7 and 8 were operated fully open with a length of 100 ft of grout-filled bags with the long side placed perpendicular to the flow. Severe scour occurred on the right side of the channel, and four bags were rolled several turns downstream. Bags should not be placed with the long side perpendicular to direction of flow. Tests with sluices 1 and 2 fully open and 5 and 6 open 7 ft each for 7 days did not show any material movement. This combination had proved especially detrimental in the prototype earlier. In general, any concentric combination of gates was found to be satisfactory with the grout-filled bags in place. If scour is not a problem downstream of the bags in the prototype due to the presence of natural rock, or if overburden scour is shallow enough that the bags will conform to the resulting bed, then any eccentric gate combination could be allowed without material moving into the basin. While not a recommended operation, said arrangement could be expected to protect against misoperation or an unorthodox gate operation for whatever reason.

Powerhouse Operation

26. Simultaneous discharges from the powerhouse (4,800 cfs) and the sluices further compound the current variations. While the 100 ft of grout-filled bags were in place, the powerhouse and a wide-open No. 3 sluice were operated for 7 days. Strong upstream currents were noted on the right side of the channel. About 5 yd^3 of material entered the trap and several yards were scattered on the bags. Severe scour occurred downstream of the bags in line with the No. 3 sluice. Grout-filled bags are not foolproof for eccentric sluice operations, which should be avoided.

27. Additional tests were conducted to determine the effect of powerhouse discharge on current patterns and scour. Flow pattern and material movement with a powerhouse flow only of 4,800 cfs for 7 days are shown in the following sketch. Combinations of sluices in conjunction with a powerhouse discharge of 4,800 cfs were tested for 7 days each, and the results are shown in the following tabulation:

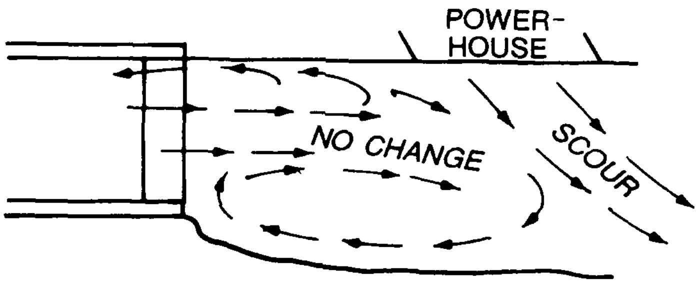


PLAN VIEW

Test No.	Total Opening, ft	Sluices
1	12	5,6
2	12	4,7
3	20	3,8
4	40	3,4,7,8
5	60	3,4,5,6,7,8
6	20	1,2
7	40	1,2,3,8

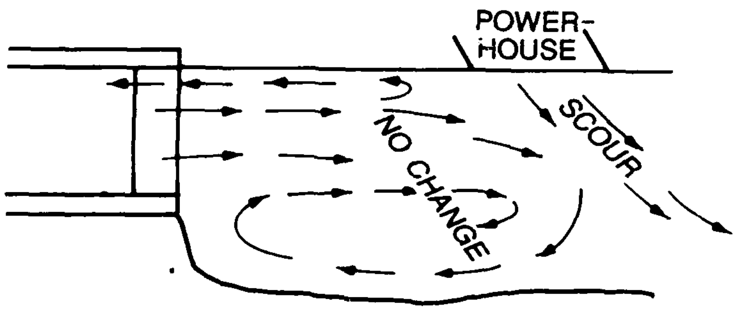
Flow patterns and results are shown in the following sketches in plan view for each test:

a. Test 1. Slight ramping at left trap wall. No noticeable material movement. Good condition.



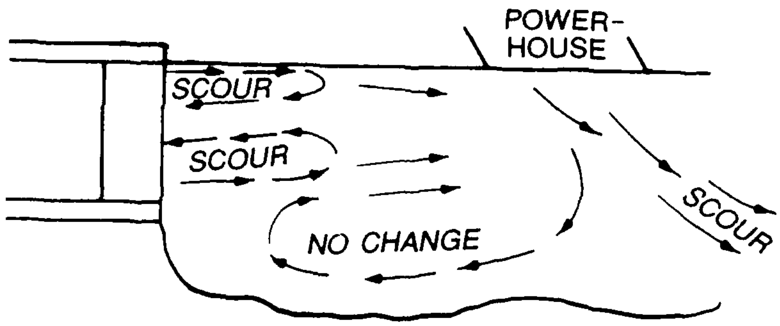
PLAN VIEW

b. Test 2. Slight bar built down middle. Slight ramping at left wall. Good condition.



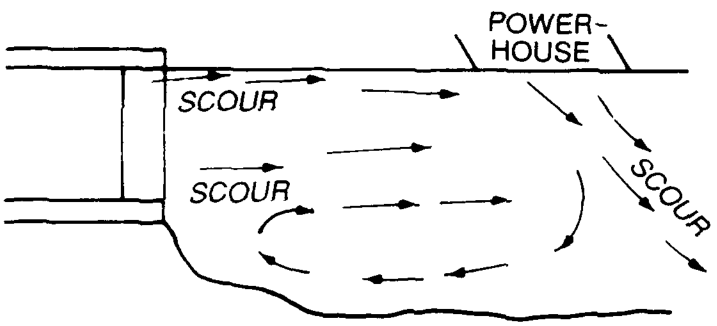
PLAN VIEW

c. Test 3. Good condition.



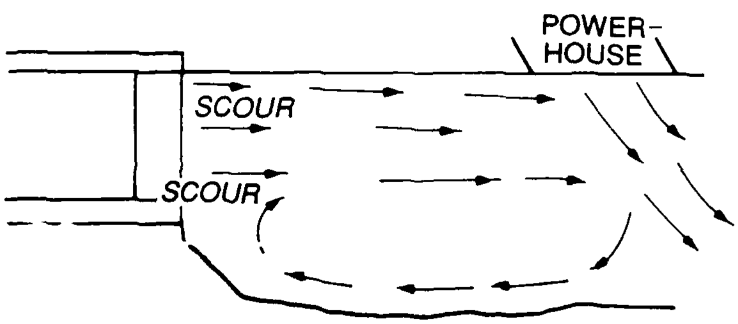
PLAN VIEW

d. Test 4. Good condition.



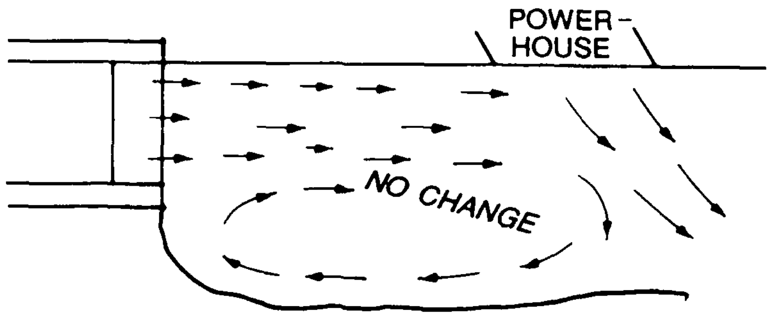
PLAN VIEW

e. Test 5. 40 yd^3 in basin, 200 yd^3 in trap. DO NOT EXCEED total sluice opening of 40 ft when powerhouse is operating.



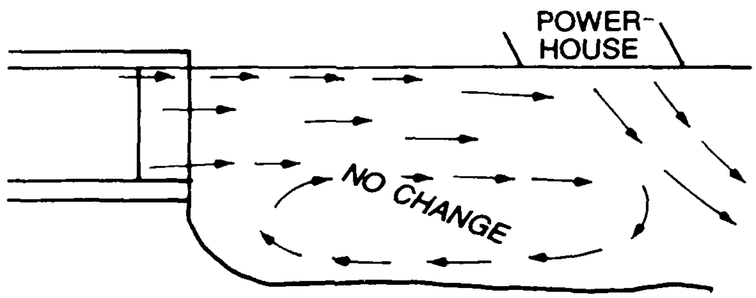
PLAN VIEW

f. Test 6. Good condition.



PLAN VIEW

g. Test 7. Good condition.



PLAN VIEW

One Upper Sluice Out Of Service

28. Tests were conducted to develop an operating schedule for the lower sluices to be used in the event that one upper sluice was out of service. With the No. 2 sluice inoperative, the following schedule was developed for satisfactory operation with the No. 1 sluice open 2, 4, 6, 7, or 10 ft:

Total Sluice Opening, ft	Lower Sluice Opening, ft
0-12	5 & 6 open equal amounts
0-20*	3 & 8 open equal amounts
21-30**	3,6, & 8 open equal amounts (do not exceed 30 ft)

* Recommended first choice.
** Recommended last choice.

These tests indicated that sluices 1, 3, and 8 open 10 ft each (30-ft total) would move material into the trap. Numbers 1, 3, 4, 7, and 8 open 8 ft each (40-ft total sluice opening) also moved material into the trap. It is recommended that no variations from this operating schedule be allowed and that efforts be made to minimize operator error.

One Lower Sluice Out Of Service

29. An operating schedule to be used if any one lower sluice is inoperative was developed and is shown in Table 4. In the event any two lower sluices are out of service, the operating schedules shown in Table 4 and in paragraphs 21 and 28 should be followed.

PART IV: DISCUSSION AND RECOMMENDATION

30. As stated earlier, the primary purpose of this study was to evaluate various methods of preventing riverbed material from entering the stilling basin and causing erosion problems. The rock trap selected as the final design, described in paragraph 16, was constructed in the prototype in the fall of 1983. Periodic inspections have indicated small amounts of rock in the trap, but in general, the trap has been most effective. Strict adherence to the operating schedule listed in paragraph 21 and minimizing of operator error are also key factors in avoiding problems.

31. In October 1985, grout-filled fabric bags were placed downstream of the trap. The bags were placed only over areas containing loose aggregate that would be susceptible to washing into the trap or stilling basin. These bags have been helpful by eliminating the source of material that can be drawn into the basin.

32. Appendix A presents the normal sluice gate-opening schedule that was developed by the Pittsburgh District from these model tests and later provided favorable results in the prototype. Five years after its implementation, the schedule provided in Appendix A continues to be the recommended method of operation. In the event of one or more sluices being out of service, recommendations given in paragraphs 28 and 29 of this report should be considered with close monitoring of the prototype operation.

33. Modification of the upper sluices is not required with installation of the debris trap and adherence to recommended gate operations.

34. A brief test was conducted with an all-spillway flow of 153,500 cfs probable maximum flood to determine if the spillway nappe would clear the bridge and fully opened gates. Although the pool reached an elevation of 1,376 (about 1 ft higher than the dam), the nappe remained beneath the bridge and gates due to the drawdown at the spillway.

Table 1

Selected Operating Conditions

Total Gate Opening, ft	Lower Sluices Number	Lower Sluices Opening, ft	Tailwater El	Operation Time prototype hours	Volume of Material Moved, yd^3
12	5,6	6	1,203.2	2.74	0
20	4,7	10*	1,204.8	2.74	
28	4,5,6,7	7	1,205.2	2.74	
28	4,5,6,7	7	1,205.2	5.0	
28	4,5,6,7	7	1,205.2	5.0	
30	3,6,8	10*	1,206.2	2.74	
60	All	10*	1,209.0	2.74	28
60	All	10*	1,209.0	5.0	9
60	All	10*	1,209.0	5.0	4
24	4,7 5,6	4 8	1,205.0	2.74	0

Note: Pool el 1,340.
* Fully open.

Table 2

Symmetrical Sluice, Rock Trap, and Sloping End Sill Tests

Total Gate Opening, ft	Lower Sluices Number	Lower Sluices Opening, ft	Tailwater El	Operation Time, hr	Volume of Material Moved into Basin, yd^3	Remarks
			Symmetrical Sluice Operation (No Trap)			
50	4,5,6,7 3,8	10* 5	1,208.5	10	9	No remolding in riverbed after preceding test
50	3,4,7,8 5,6	10* 5	1,208.5	10	15	
50	3,5,6,8 4,7	10* 5	1,208.5	10	6	
60	3,4,5,6,7,8	10*	1,209.0	10	10	
			Rock Trap (30 ft Wide by 10 ft Deep)			
60	3,4,5,6,7,8	10*	1,209.0	10	0	No remolding
	3,4,5,6,7,8	10*	1,209.0	10	0	No remolding
	3,4,5,6,7,8	10*	1,209.0	10	3	±800 yd^3 in trap
	3,4,5,6,7,8	10*	1,209.0	10	0	Clean trap
	3,4,5,6,7,8	10*	1,209.0	10	0	±400 yd^3 in trap

(Continued)

Note: Pool el 1,340.
* Fully open.

Table 2 (Concluded)

Total Gate Opening, ft	Lower Sluices Number	Lower Sluices Opening, ft	Tailwater El	Operation Time, hr	Volume of Material Moved into Basin, yd^3	Remarks
			Sloping End Sill			
60	3,4,5,6,7,8	10*	1,209.0	10	20	Long end sill slope**
	3,4,5,6,7,8	10*	1,209.0	10	12	45-deg end sill slope†
	3,4,5,6,7,8	10*	1,209.0	10	35	Square end sill
	3,4,5,6,7,8	10*	1,209.0	5	60	Long end sill slope; material 3 ft below sill for 60 ft
60	3,4,5,6,7,8	10*	1,209.0	5	20	45-deg end sill slope; material 3 ft below sill for 60 ft
60	3,4,5,6,7,8	10*	1,209.0	5	55	Square end sill; material 3 ft below sill for 60 ft

* Fully open.

** End sill sloped from downstream end of baffle blocks up to top edge of existing end sill.

† End sill sloped from top, upstream edge of existing end sill down to basin floor on 45-deg angle.

Table 3

Rock Trap Tests

Total Gate Opening, ft	Lower Sluices Number	Lower Sluices Opening, ft	Tailwater El	Operation Time, days	Volume of Material Moved into Basin, yd^3	Volume of Material Moved into Trap, yd^3
			Trap Type 1			
60	3,4,5,6,7,8	10*	1,209.0	8.1	0	25
40	3,4,7,8	10*	1,209.0	0.167		35
40	3,5,6,8	10*	1,207.5	0.083		30
40	3,5,6,8	10*	1,207.5	7		40
			Trap Type 2 (Adopted)			
60	3,4,5,6,7,8	10*	1,209.0	7		40
40	3,5,6,8	10*	1,207.5	7		35
40	3,5,6,8	10*	1,207.5	7		40
40	3,4,6,8	10*	1,207.5	7		10
40	4,5,6,7	10*	1,207.5	7		200
12	5,6	6	1,203.2	0.417		0
20	3,8	10*	1,204.8	0.417		0
20	4,7	10*	1,204.8	0.417		0

(Continued)

Note: Pool el 1,340.

Trap types:

1 - Trap 30 ft wide with 14-ft-high by 30-ft-wide wall.
2 - Trap 26 ft wide with 10-ft-high by 4-ft-wide wall.
3 - Trap 25 ft wide with 8-ft-high by 4-ft-wide wall (District Plan B).
4 - Trap 25 ft wide with wall 10 ft high on left and 8 ft high on right (Plan C).
5 - Trap 25 ft wide with variable invert and wall elevation (Plan A).

* Fully open

Table 3 (Concluded)

Total Gate Opening, ft	Lower Sluices Number	Lower Sluices Opening, ft	Tailwater El	Operation Time, days	Volume of Material Moved into Basin, yd^3	Volume of Material Moved into Trap, yd^3
			Trap Type 2 (Adopted) (Continued)			
22	4,7	3	1,204.8	4.667	0	10
	5,6	8				
24	4,7	4	1,205.0	4	0	35
	5,6	8				
28	4,5,6,7	7	1,205.5	4	3	115
30	3,6,8	10*	1,206.0	4	0	5
20	4,7	10*	1,204.8	4	0	10
			Trap Type 3			
40	4,5,6,7	10*	1,207.5	7	85	540
40	3,5,6,8	10*	1,207.5	7	0	240
			Trap Type 4			
40	3,4,6,8	10*	1,207.5	7	0	280
			Trap Type 5			
40	3,4,5,6,7,8	6-2/3	1,207.5	7	15	15
40	3,5,6,8	10*	1,207.5	7	12	240

* Fully open.

Table 4

Operating Schedule for One

Sluice out of Service

Sluice Out of Service*	Total Gate Opening, ft	Recommended Gates and Openings: Gates	Openings, ft
3**	0-12†	5	6
		6	6
	0-12†	4	6
		7	6
	0-20	1	10
		2	10
	0-20	4	10
		5	2
		8	8
4	0-12†	5	6
		6	6
	0-12	3	6
		7	4
		8	2
	0-20†	3	10
		8	10
	0-20	1	10
		2	10
	21-40	1	10
		2	10

(Continued)

* If No. 3 or No. 8 is out of service, 40-ft total gate opening can be achieved only by using No. 1 and No. 2. Since No. 1 and No. 2 are not normally operated for high values of total gate openings, consideration should be given to providing any additional flow from the powerhouse, if needed.

** Field tests conducted on the prototype during December 1984, with sluice No. 8 out of service, indicated no material transport when the following percentages of total gate openings were distributed between 0 and 25 ft:

	3	4	5	6	7	8
No. 8 out of service	30	10	10	10	40	0
No. 3 out of service	0	40	10	10	10	30

It is believed that the reverse order would apply (as shown) for No. 3 out of service as well. The same percentages of total opening shown should be used for smaller gate openings not listed. Refer to Appendix A, Remark 3, page A2.

† Preferred settings.

Table 4 (Continued)

Sluice Out of Service	Total Gate Opening, ft	Recommended Gates and Openings: Gates	Recommended Gates and Openings: Openings, ft
4 (continued)		3	10
		8	10
	21-40	3	10
		5	10
		6	10
		8	10
5	0-12†	4	6
		7	6
	0-12	3	1
		6	10
		8	1
	0-20†	3	10
		8	10
	0-20	1	10
		2	10
	21-40†	3	10
		4	10
		7	10
		8	10
	21-40	1	10
		2	10
		3	10
		8	10
6	0-12†	4	6
		7	6
	0-12	3	1
		5	10
		8	1
	0-20	3	10
		8	10
	0-20	1	10
		2	10
	21-40	1	10
		2	10
		3	10
		8	10

(Continued)

† Preferred settings.

Table 4 (Concluded)

Sluice Out of Service	Total Gate Opening, ft	Recommended Gates and Openings: Gates	Openings, ft
6 (continued)	21-40†	3	10
		4	10
		7	10
		8	10
7	0-12†	5	6
		6	6
	0-12	3	2
		4	4
		8	6
	0-20†	3	10
		8	10
	0-20	1	10
		2	10
	21-40	1	10
		2	10
		3	10
		8	10
	21-40	3	10
		5	10
		6	10
		8	10
8**	0-12†	5	6
		6	6
	0-12†	4	6
		7	6
	0-20	3	8
		6	2
		7	10
	0-20	1	10
		2	10

** See explanation on Sheet 1.
† Preferred settings.

(Sheet 3 of 3)

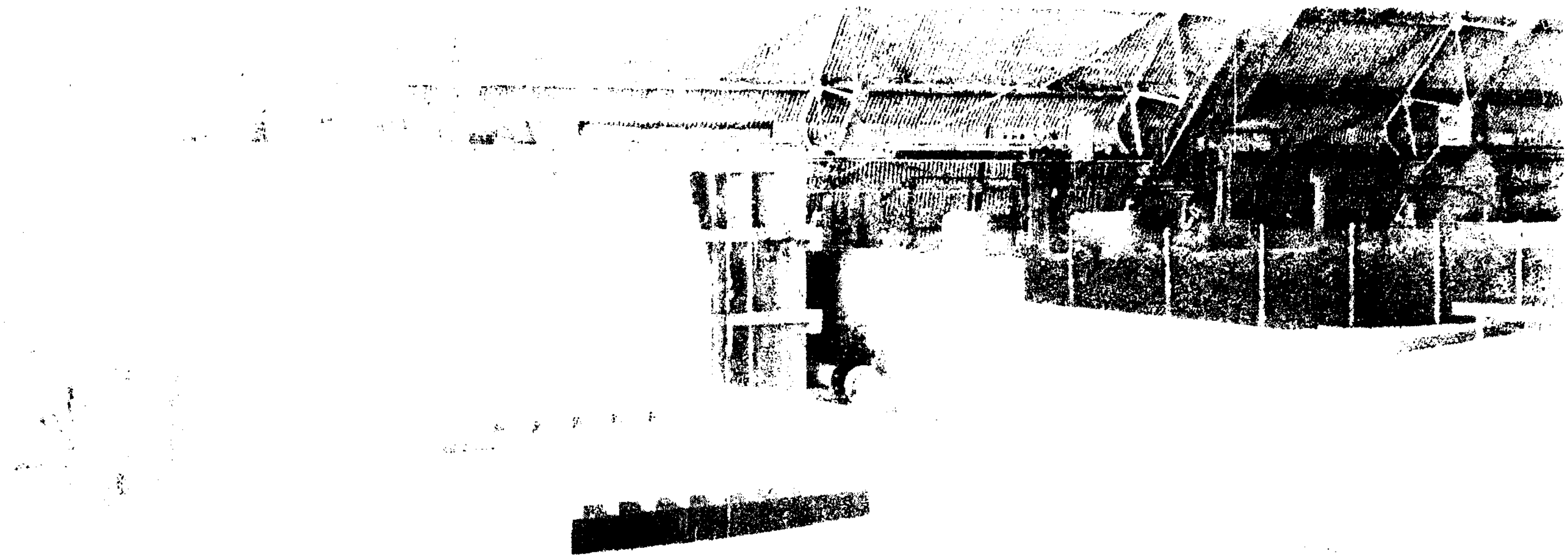


Photo 1. Kinzua Dam model as built

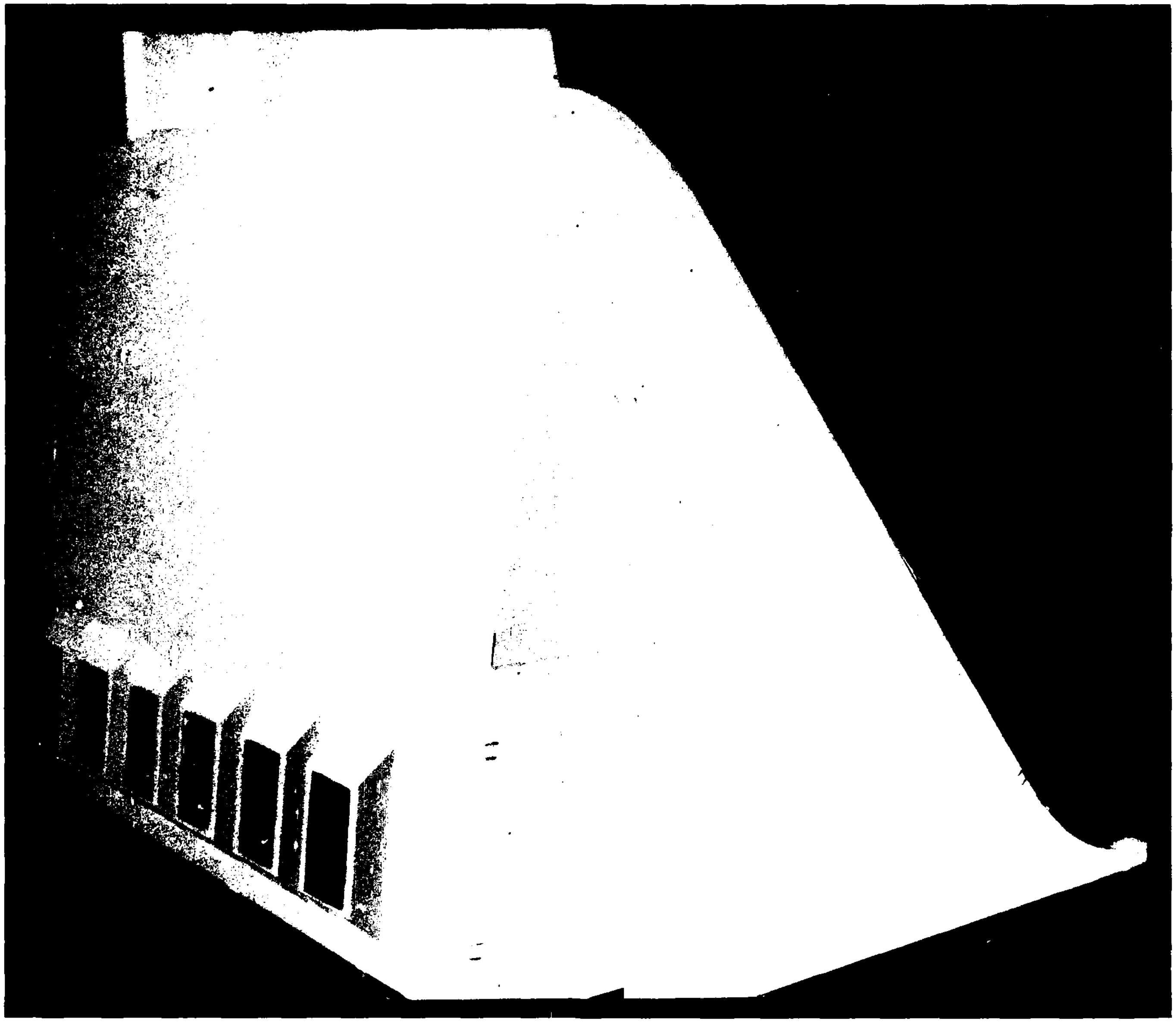


Photo 2. Crest and spillway after joining two halves

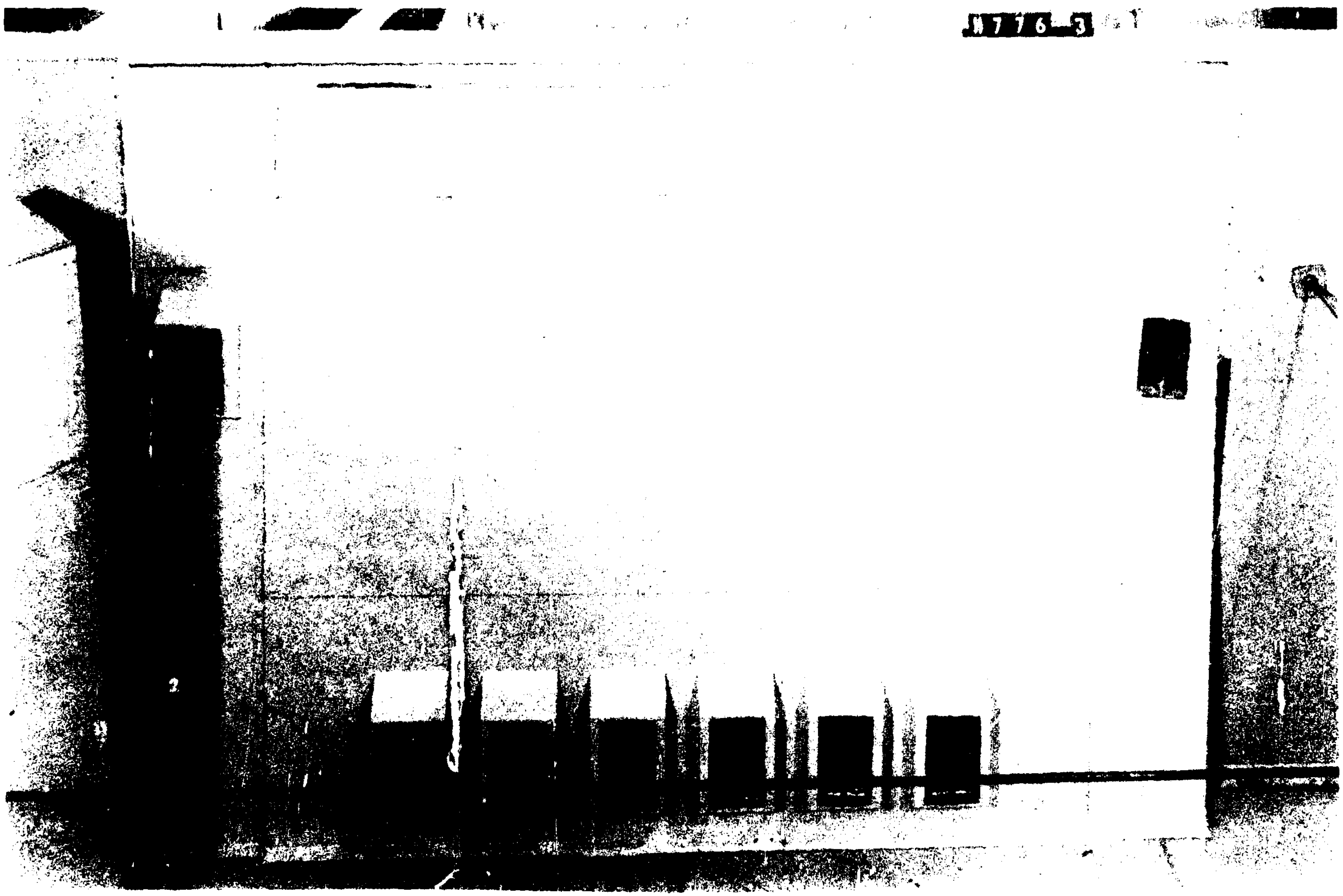
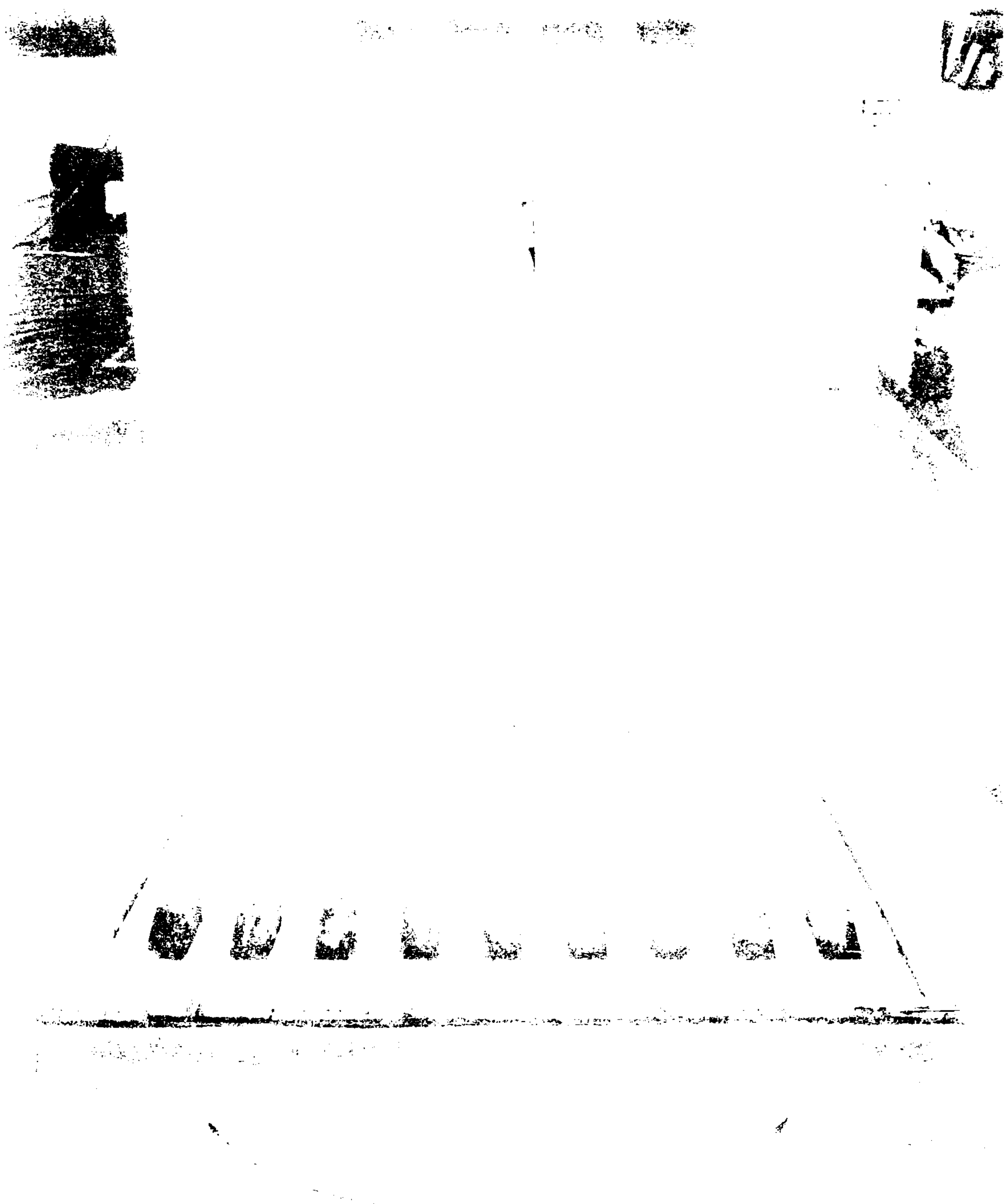


Photo 3. Looking downstream at structure



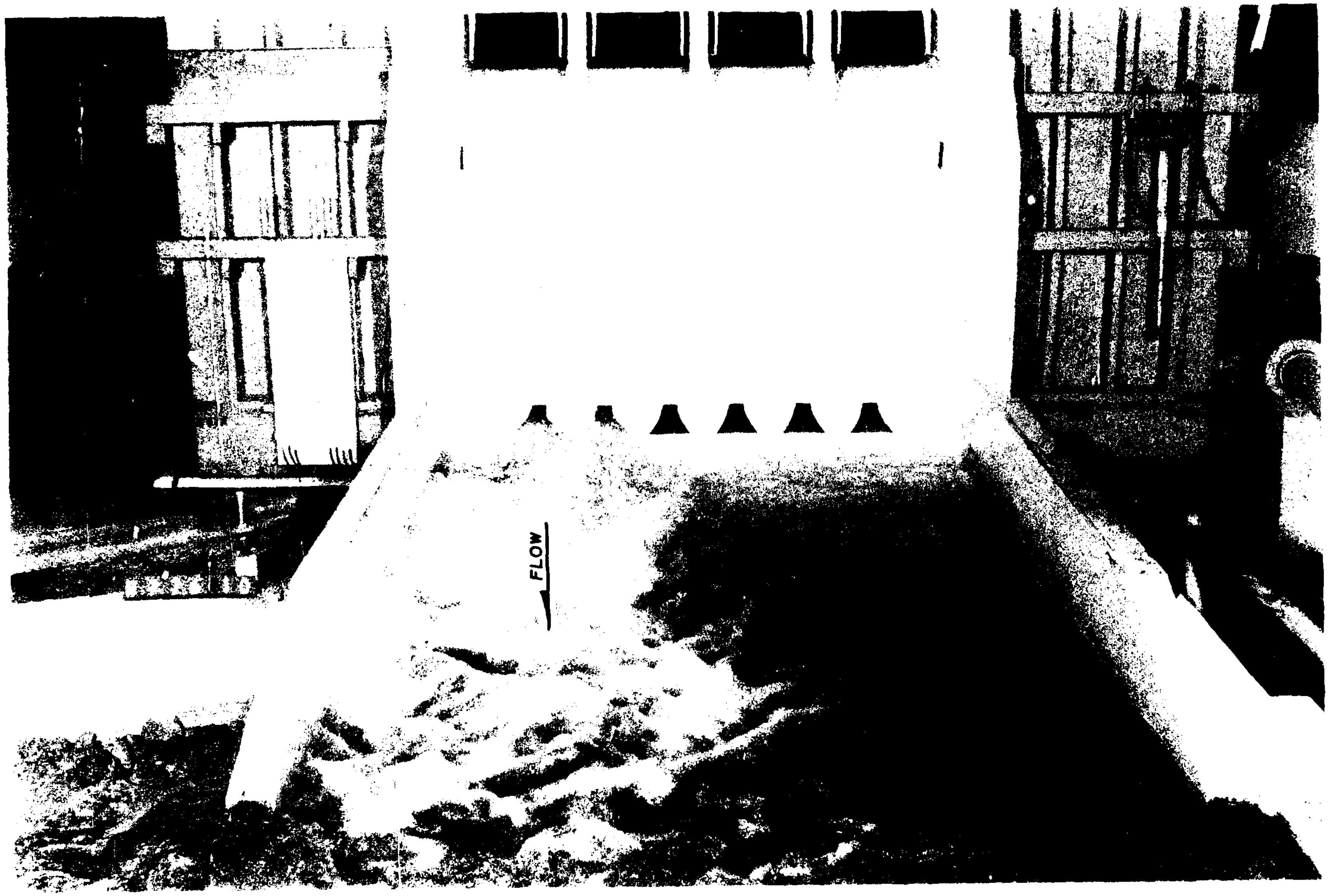


Photo 5. Sluices 7 and 8 fully open 10 ft each

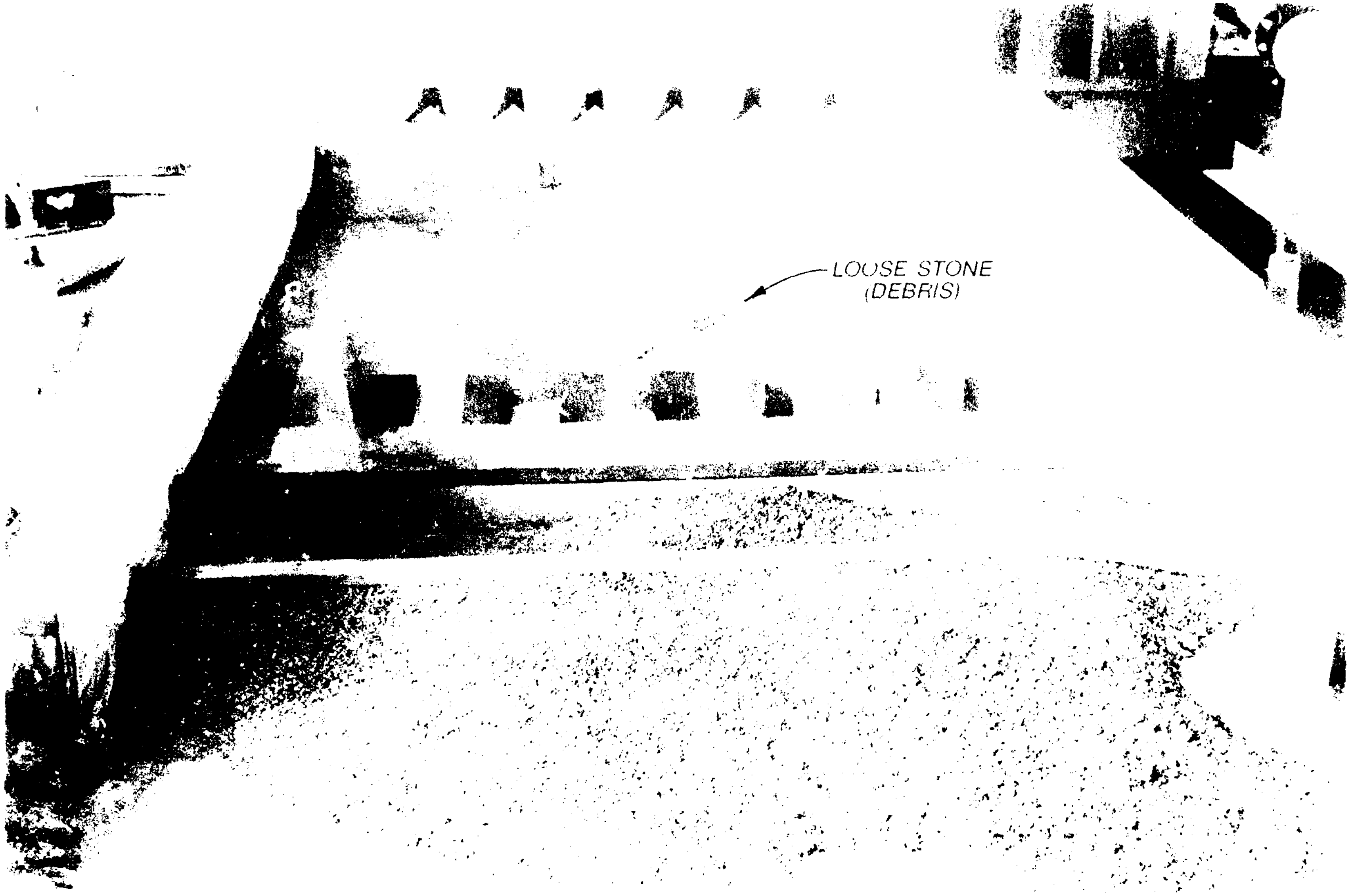


Photo 6. [illegible] Dam after [illegible] prototype days operation with sluices [illegible] and 8 fully open

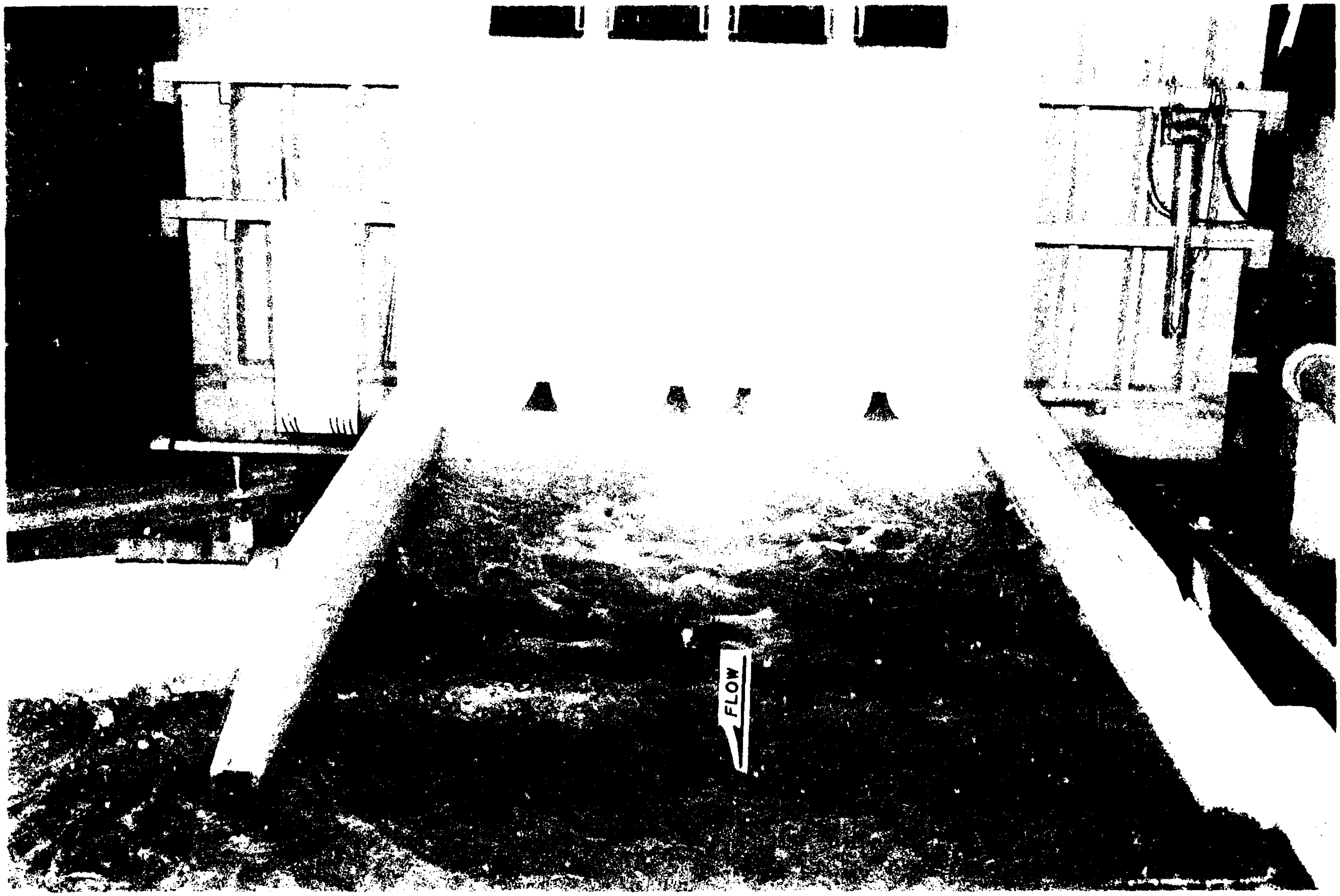


Photo 7. Sluices 1 and 2 fully open

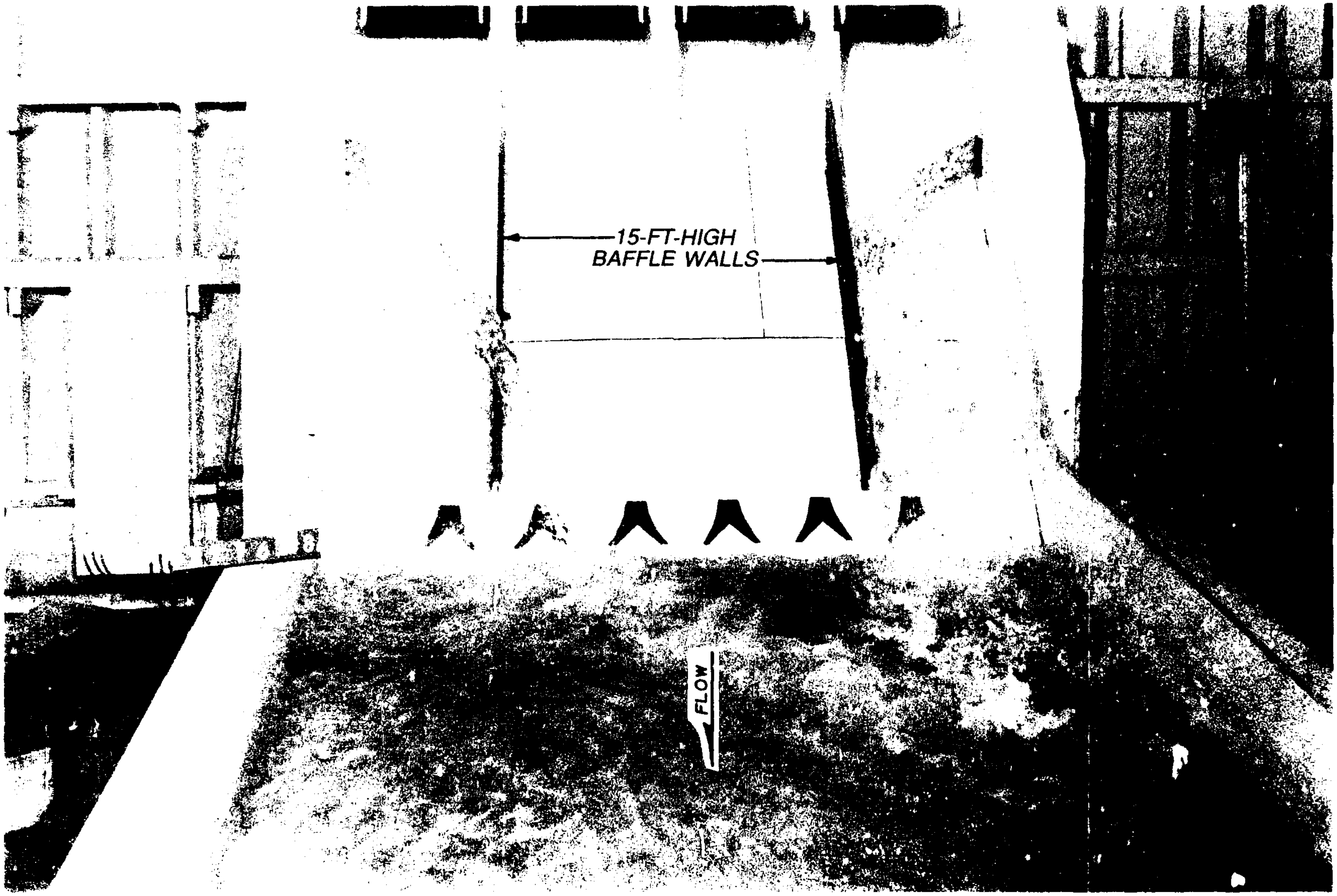


Photo 8. Right side shows modification 6; left side is unmodified. Fifteen-foot-high baffle walls are visible on both sides of the spillway

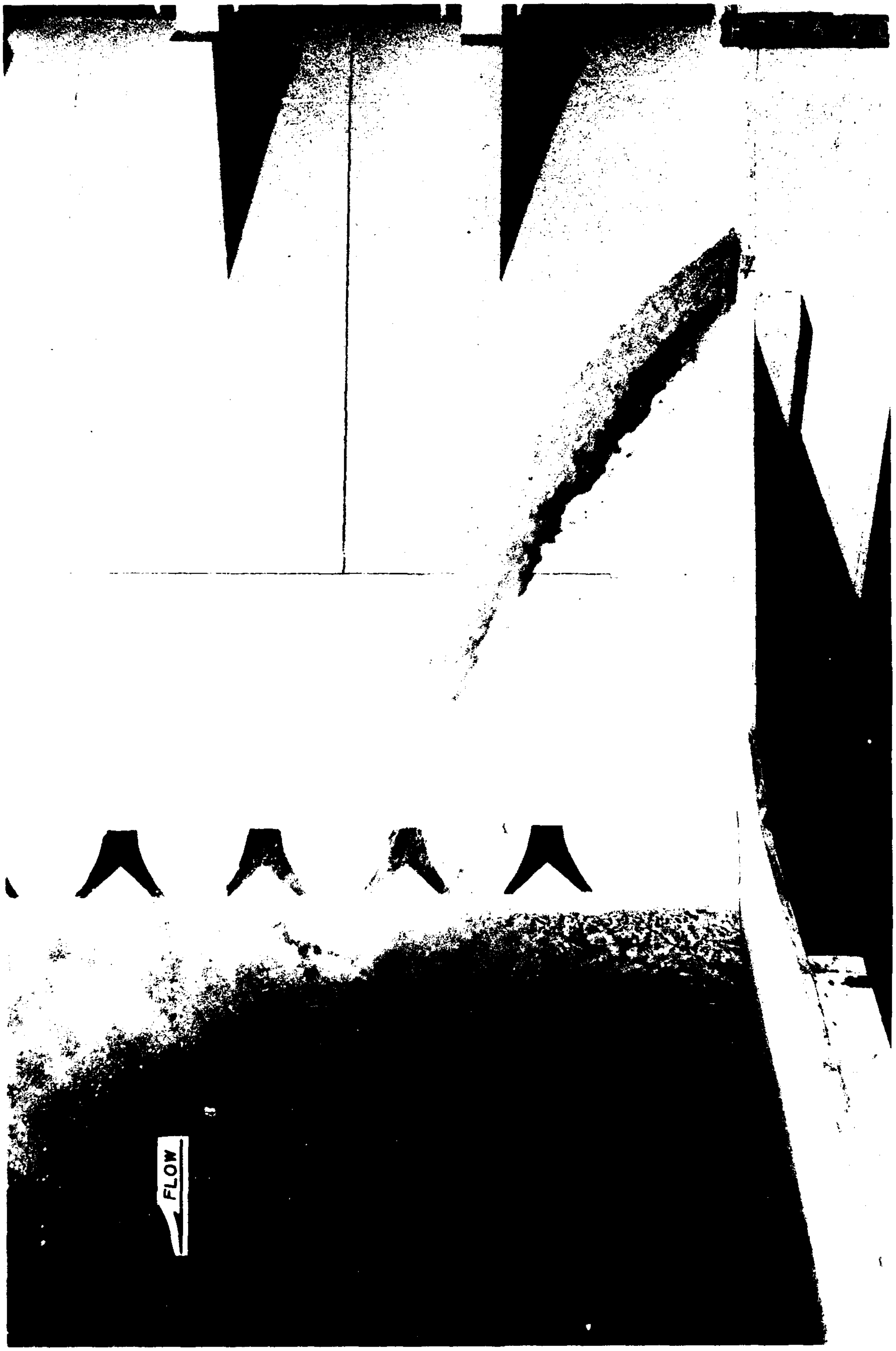
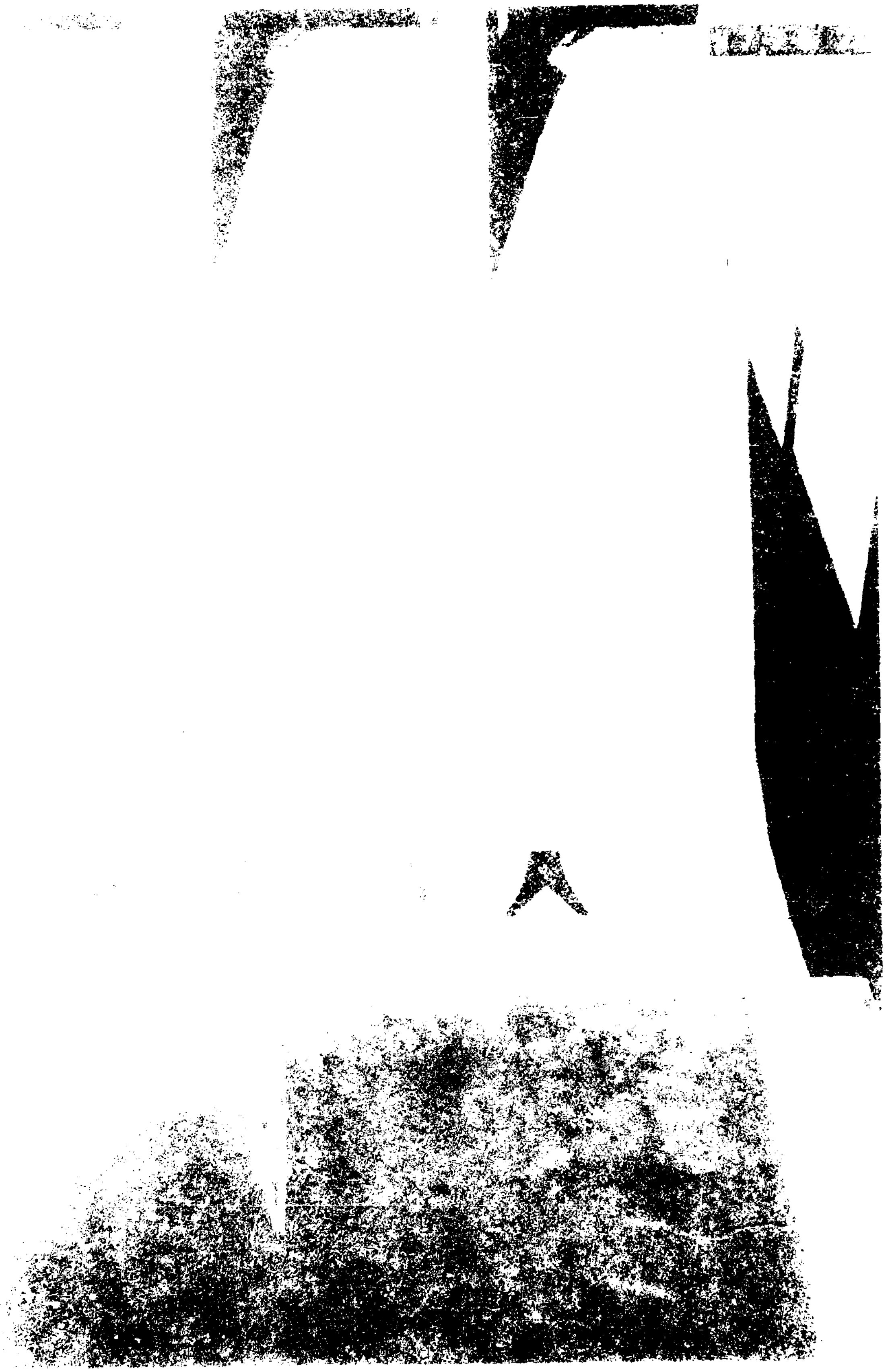


Photo 9. Sluice gate in modification 1 fully open



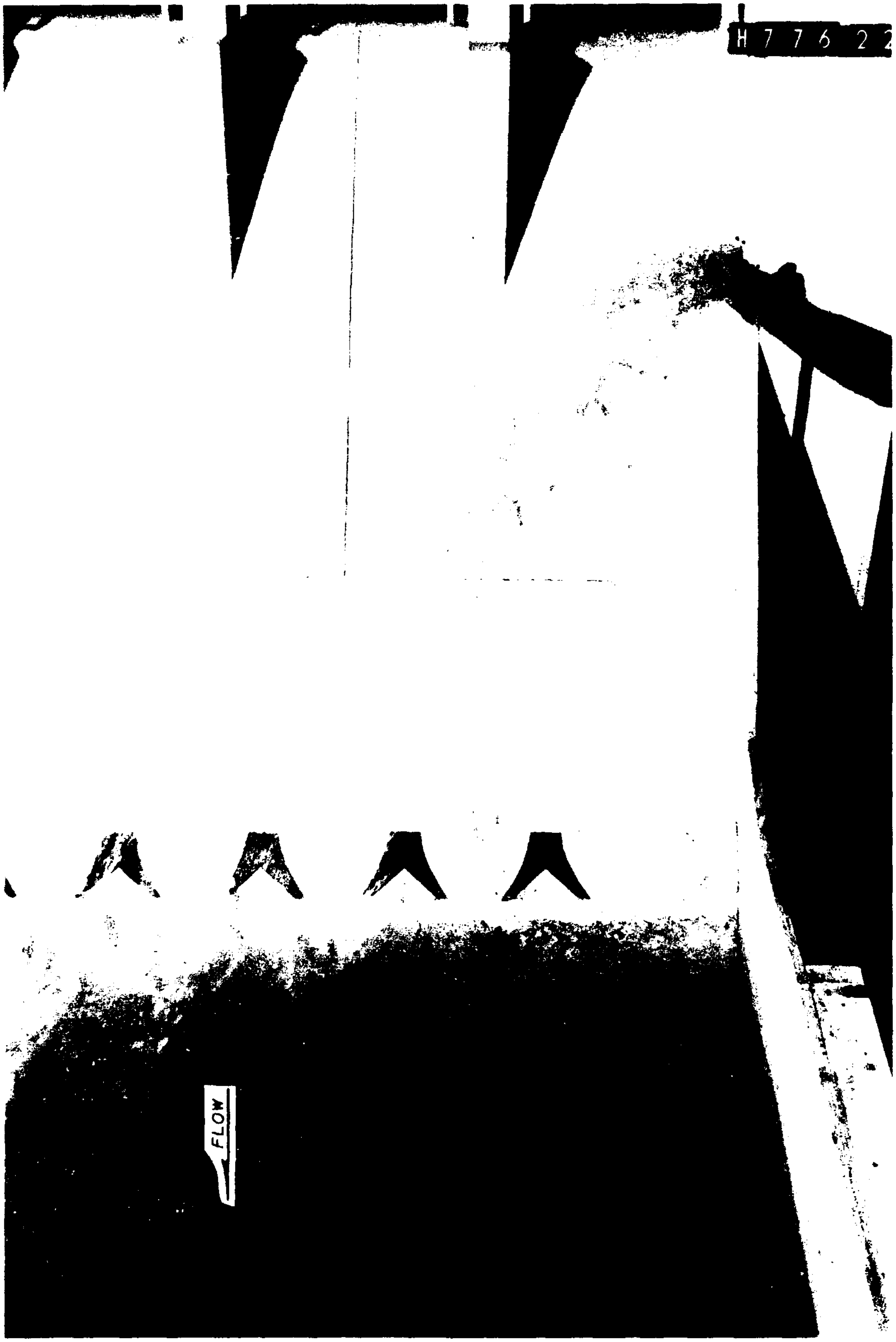


Photo 11. Sluice gate in modification 1 at 90-deg angle


H7762

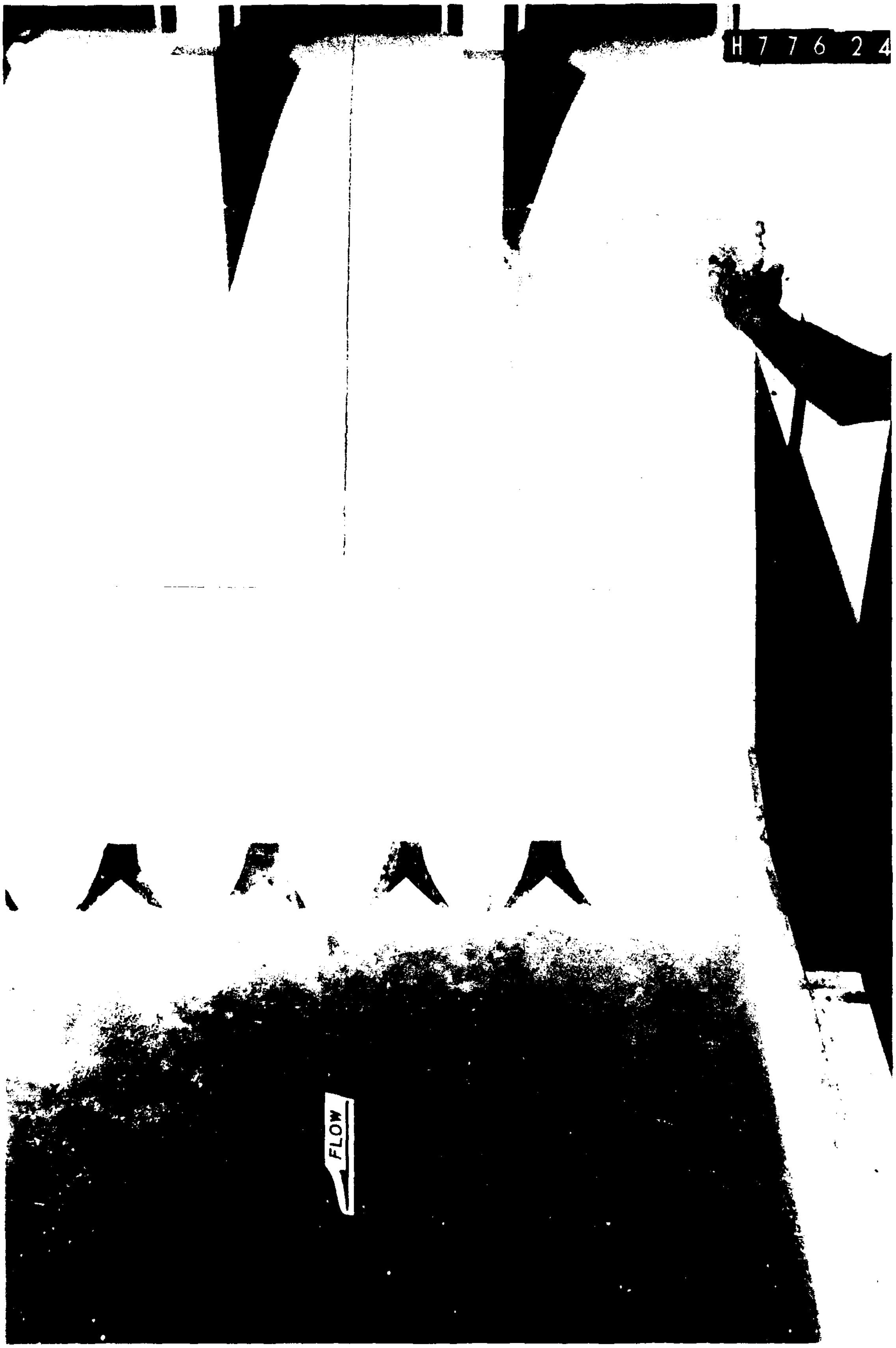


Photo 13. Sluice gate in modification 1 at 130-deg angle from downstream wall

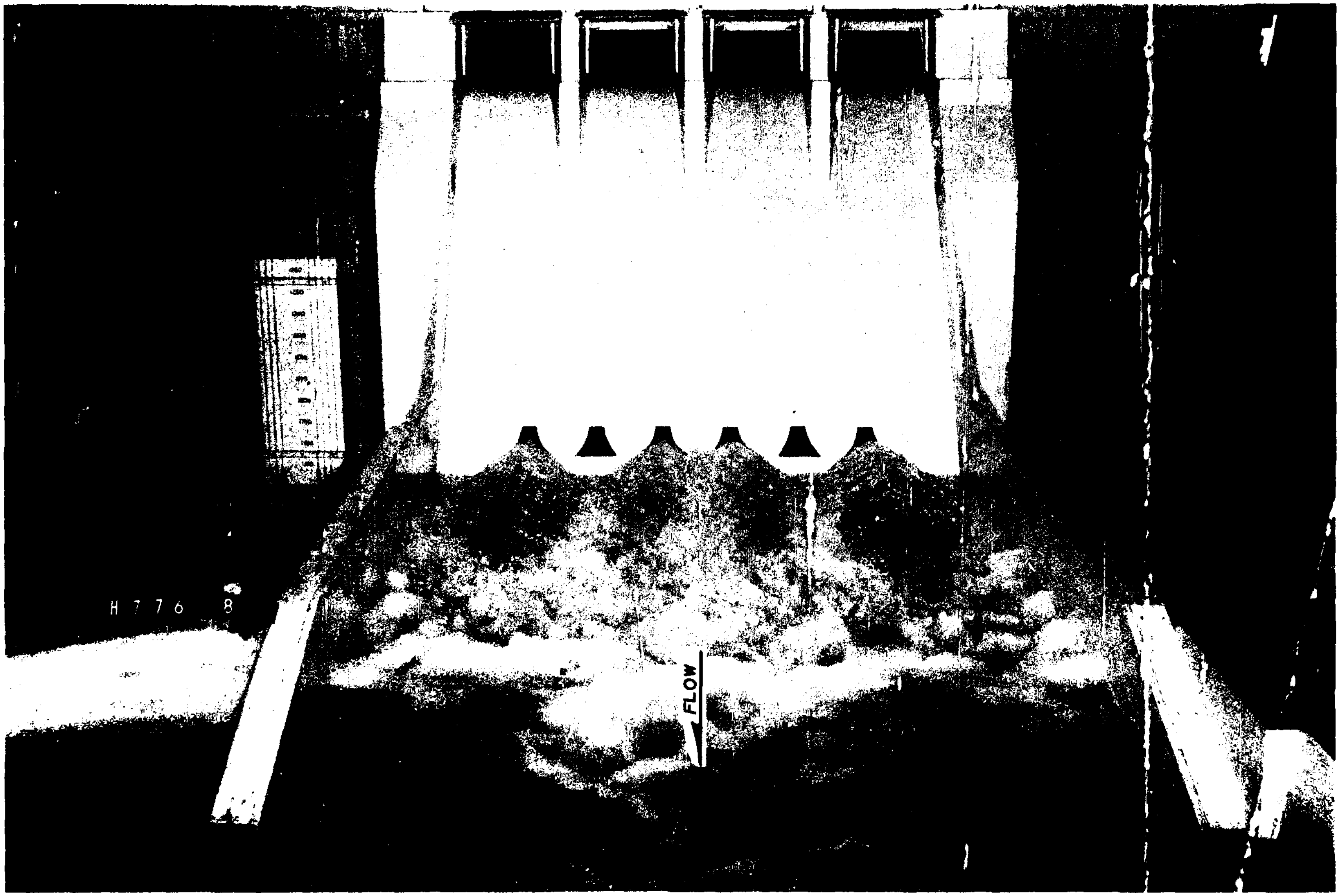


Photo 14. Sluices 3, 5, 6, and 8 open 7 ft each

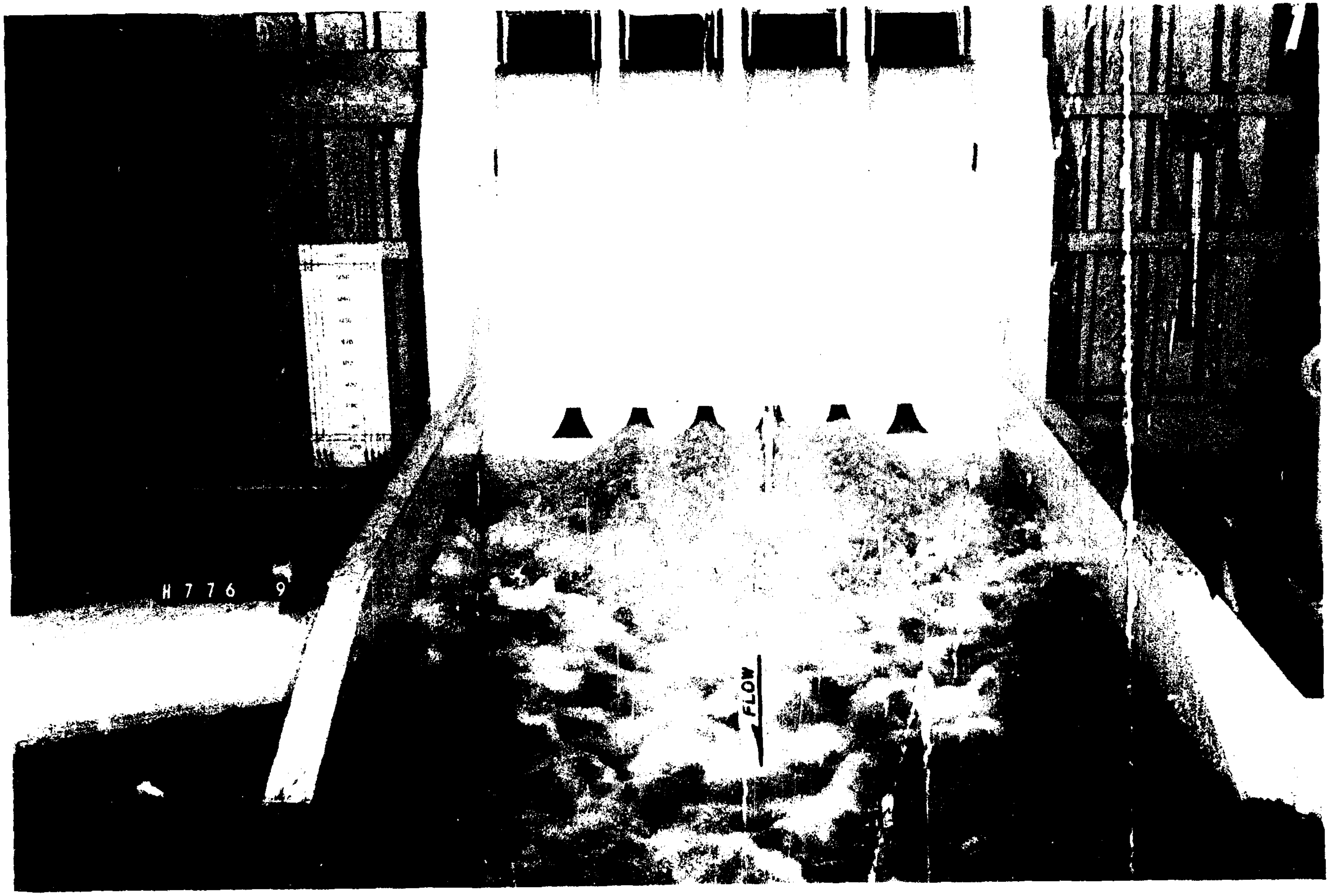


Photo 15. Sluices 4, 5, 6, and 7 open 7 ft each

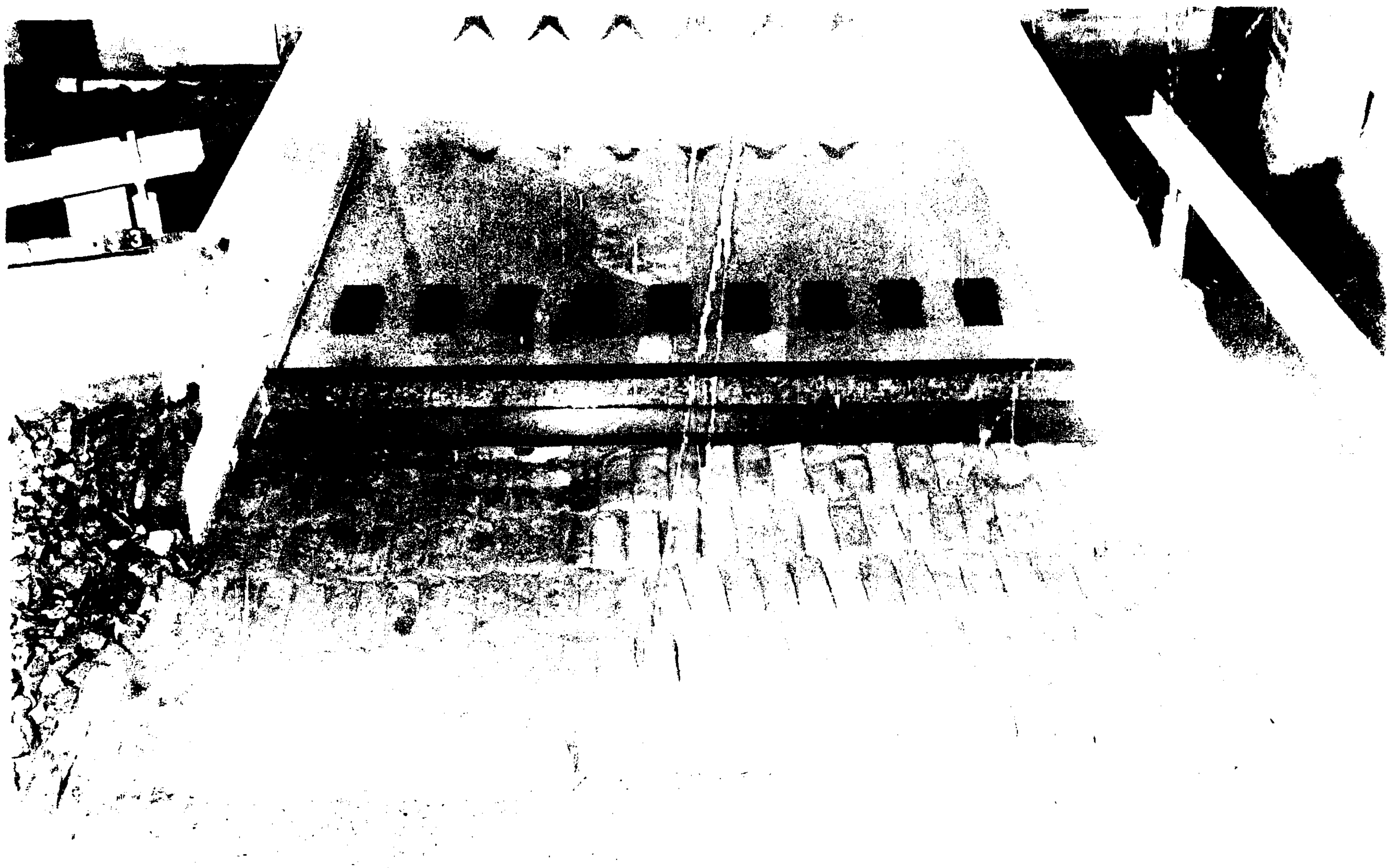
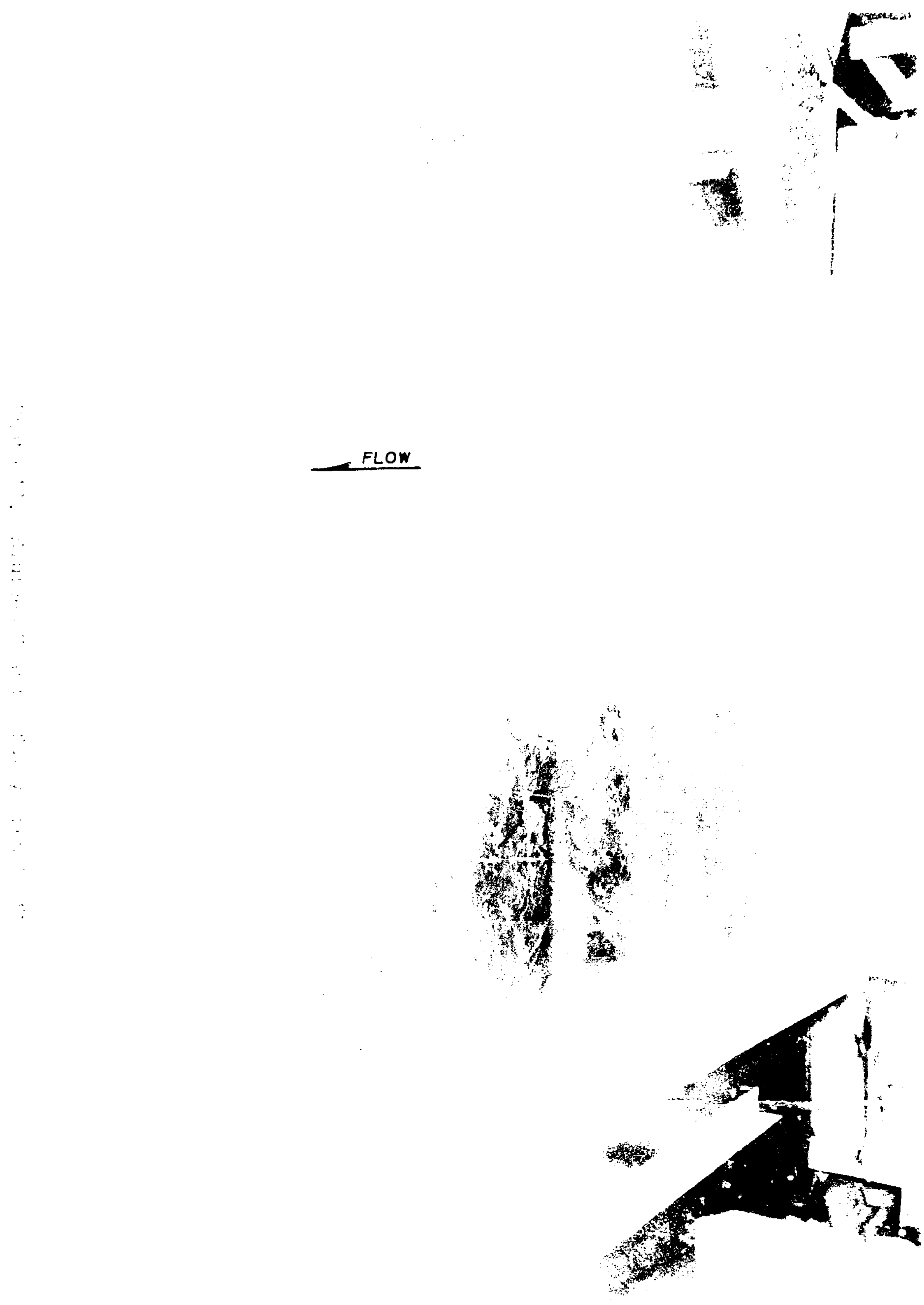
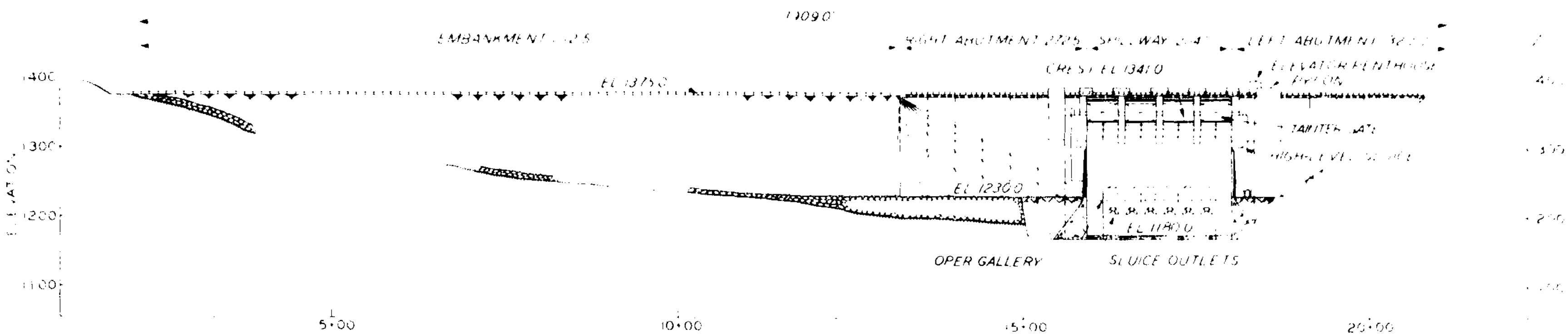
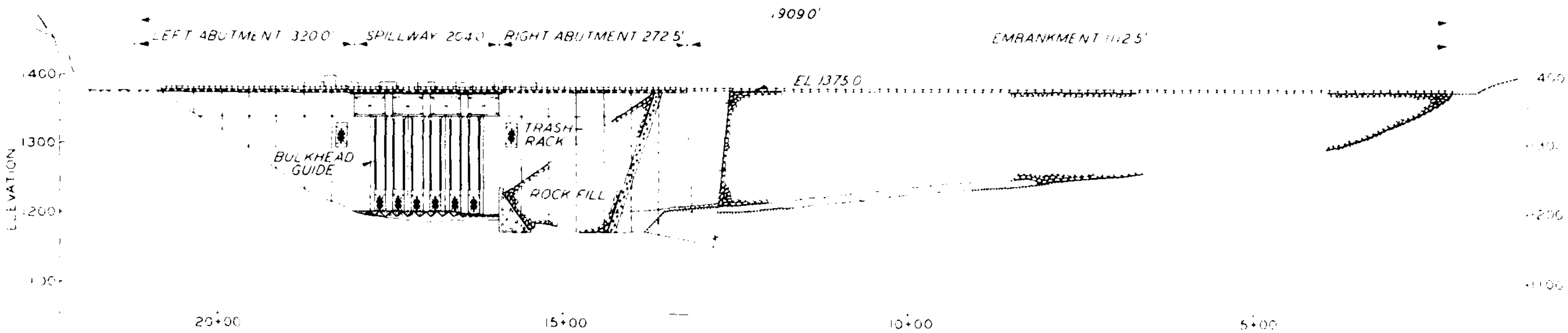


Photo 16. Grout-filled bags downstream of trap


FLOW



DOWNSTREAM ELEVATION

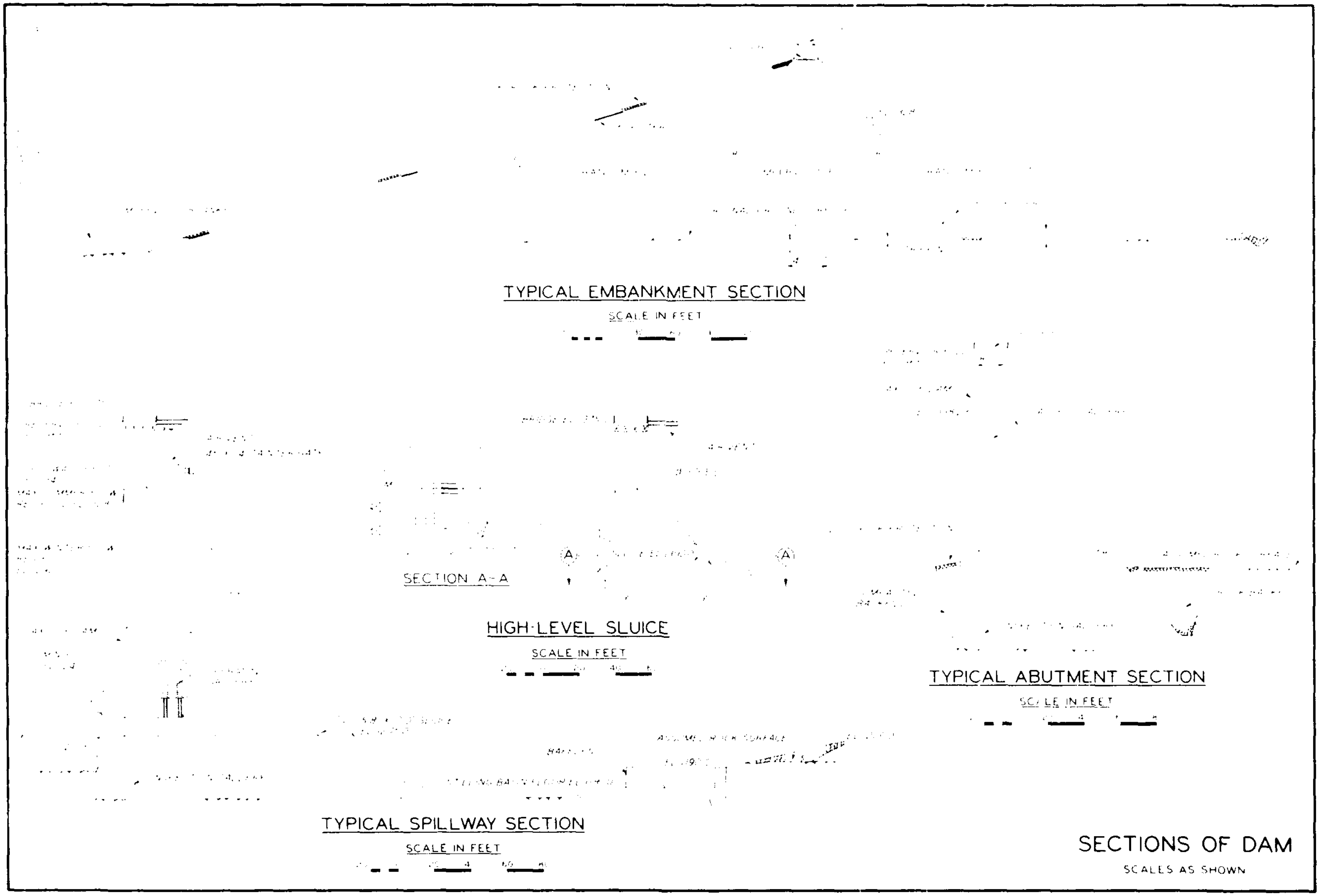


UPSTREAM ELEVATION

SECTIONAL ELEVATIONS OF DAM

SCALE AS SHOWN

PLATE 2


TYPICAL EMBANKMENT SECTION
SCALE IN FEET
SECTION A-A
HIGH-LEVEL SLUICE
SCALE IN FEET
TYPICAL ABUTMENT SECTION
SCALE IN FEET
TYPICAL SPILLWAY SECTION
SCALE IN FEET
SECTIONS OF DAM
SCALES AS SHOWN

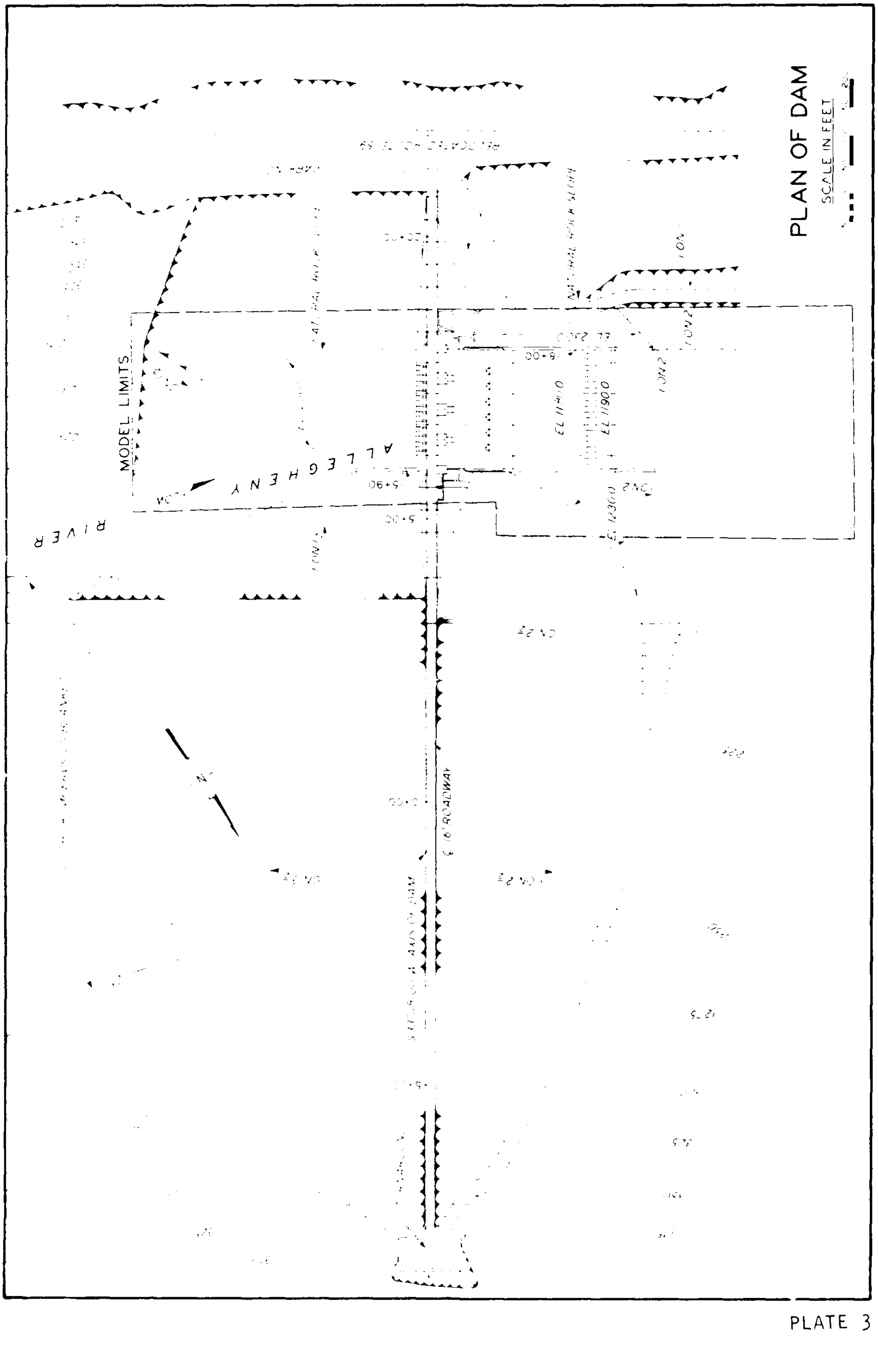
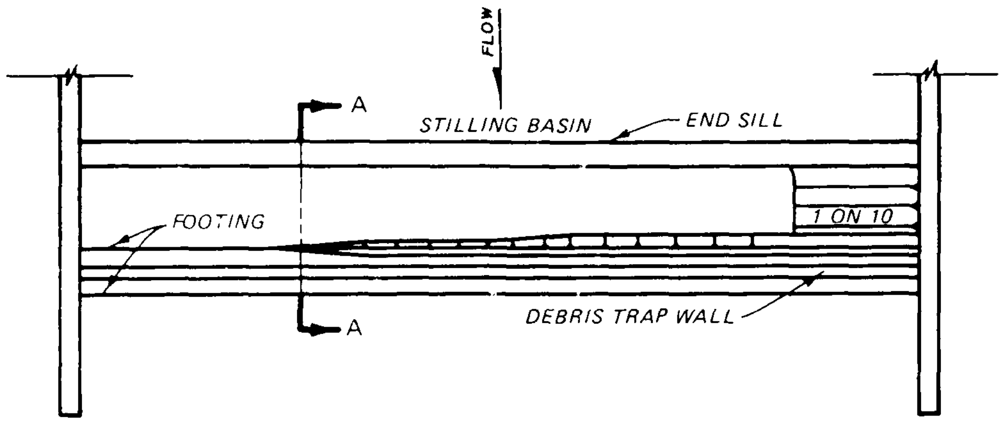
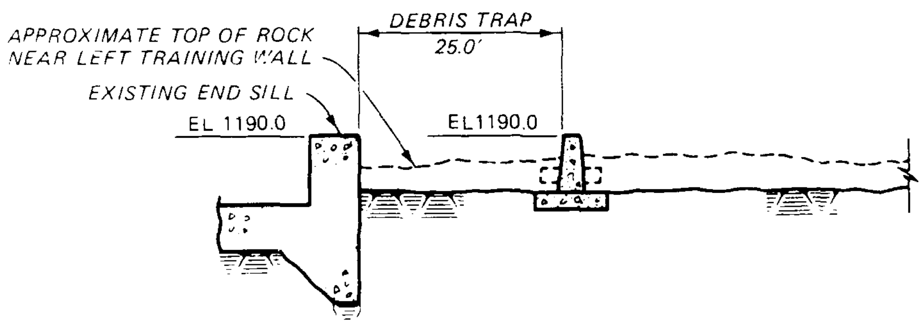

PLAN OF DAM
SCALE IN FEET
MODEL LIMITS
ALLEGHENY
RIVER
16' ROADWAY

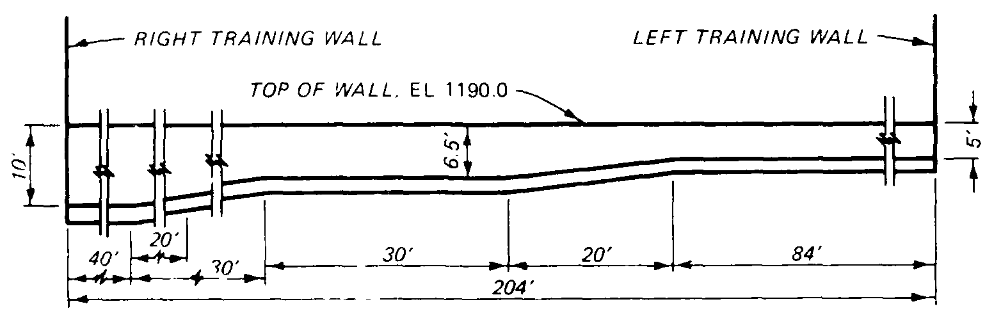
PLATE 3



PLAN



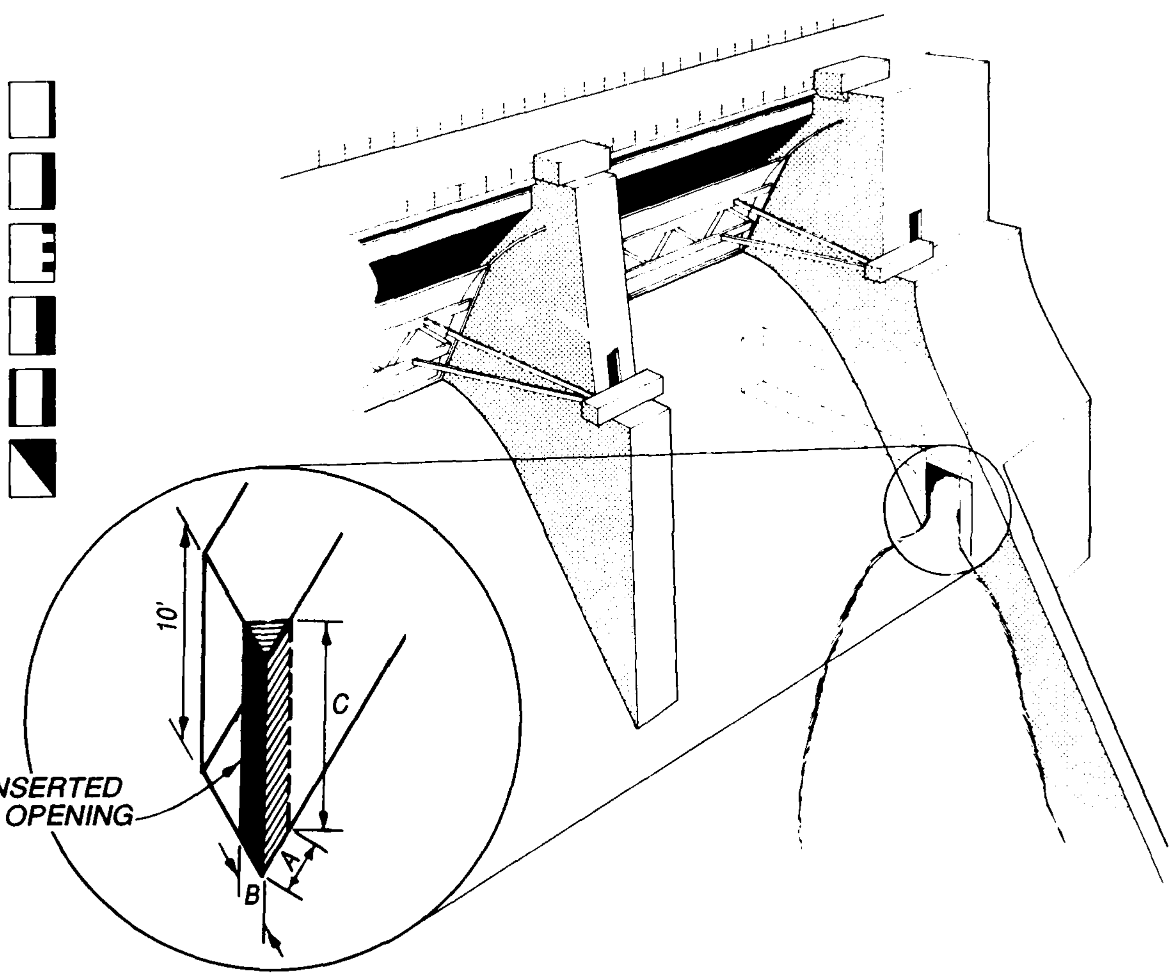
SECTION AA



DOWNSTREAM ELEVATION

FINAL DESIGN
DEBRIS TRAP

TEST NO	LENGTH (A)	WIDTH (B)	HEIGHT (C)
1	3.3'	1.2'	10'
2	6.6'	2.4'	10'
3	6.6'	2.4'	10'*
	*3 pieces 1.67' each		
4	10'	3.6	10'
5	#2 outside, #1 inside		
6	5'	—	—



UPPER SLUICE MODIFICATIONS

APPEXDIX A: KINZUA DAM GATE OPERATION SCHEDULE
FOR SLUICE GATES

PART I. LOWER SLUICES - RECOMMENDED SCHEDULE.

Total Opening, ft, Required to Pass Outflow from Dam	Use Gates Shown To Divide Total Opening	
0-12	5 & 6	Equally open
0-12	4 & 7	Equally open
0-20	3 & 8	Equally open
21-40	3, 4, 7, & 8	Equally open
*41-60	3, 4, 5, 6, 7, & 8	Equally open

PART II. UPPER SLUICES AND UPPER-LOWER COMBINATIONS - RECOMMENDED SCHEDULE.

Total Opening, ft, Required to Pass Outflow from Dam	Use Gates Shown To Divide Total Opening	
0-20	1 & 2	Equally open
21-40	1 & 2	Fully open
	3 & 8	To equally divide remainder

PART III. ALTERNATIVE SCHEDULE FOR LOWER SLUICES - USE ONLY WHEN GATES RECOMMENDED IN PART I ARE OUT OF SERVICE.

Total Opening, ft, Required to Pass Outflow from Dam	Use Gates Shown To Divide Total Opening	
13-20	4 & 7	Equally open
13-20	5 & 6	Equally open
21-30	3, 5, & 8	Equally open
21-30	3, 6, & 8	Equally open
21-40	3, 5, 6, & 8	Equally Open

PART IV. THE FOLLOWING LOWER SLUICE OPERATIONS ARE NOT RECOMMENDED AND SHOULD BE AVOIDED WHEN POSSIBLE.

Total Opening, ft, Required to Pass Outflow from Dam	Use Gates Shown To Divide Total Opening	
0-40	4, 5, 6, & 7	Equally open and unequal combinations
0-40	3, 4, 5, 6, 7, & 8	Equally open

Remarks

1. Parts III and IV were seen in the 1983 model study to move greater amounts of bed material into the debris trap (located on the downstream side of the end sill) necessitating more frequent cleanouts; the District office should be notified (412-644-6847) if either is used at any time. Vigilance is imperative to prevent transport of scouring material into the stilling basin should the trap fill prematurely using Parts III and IV.

*2. It is recommended that normal operation be limited to 40 feet of total opening when Reservoir Regulation Section finds this to be possible via early or subsequent storage compensations.

3. Opening and closing must be done in steps of 1/2 foot or less to keep all conduits balanced to prevent eccentric flow patterns from bringing damaging bed material into the stilling basin. For example, if the total opening is changed from 40 feet to 32 feet using gates 3, 4, 7, and 8, it will be necessary to close each gate from 10 feet to 8 feet. First, close gate No. 8 to 9.5 feet, then gate No. 3 to 9.5 feet, then gates No. 7 and No. 4, in turn, to 9.5 feet also. When all gates are even at 9.5 feet, then step down similarly another 1/2 foot to 9 feet for all gates and so on until all gates are open 8 feet.

4. If power discharge to the tailwater changes any of the above, it will be necessary to change settings to that the total opening from the dam at any time will conform to the schedule.

5. In changing from small total openings to large total openings, or vice versa, use sequence Nos. 5-6, 4-7, 3-8 to open and reverse (8-3, 7-4, 6-5) to close.

6. Overlap in total feet of opening is presented to reduce the number of gate movements during frequent power load changes at Seneca Station.

7. Ranges of operating openings need not be consecutive. For example, if total opening is 10 feet (5 and 6 each open 5 feet) and new operation requires 18 feet total, any of the alternative setting ranges may be selected in anticipation of subsequent changes in power and outflow requirements for the period involved, so long as the 1/2-foot steps and changeover sequence in paragraph 3 are observed.